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Science More or Less*

By C. C. FURNAS

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IN 1927 the Right Reverend Edward Arthur Burroughs created an academic furor by requesting the scientists of the world to go on a holiday for ten years in order to give the world an opportunity to catch up. The ten years are almost over and the world has not shown the slightest indication of a willingness to follow his advice—not even for a moment, much less for ten years. The remedy for a sick world that lags behind certainly does not consist in plugging up the source of knowledge; but the problem of maladjustments which the Reverend Mr. Burroughs was trying to solve still remains.

Down in Memphis, Tennessee, the Rust brothers, John and Mack, have a cotton picker on exhibition. Ten more have been made and were successfully used for the harvesting of a considerable number of bales of cotton during the season just closed. The picker is not yet entirely satisfactory—it takes in too much trash, leaves and dirt, with the cotton. But there is every reason to believe that in a short time the Rust brothers will have a picker that is entirely satisfactory. Since the Civil War 750 patents have been granted on cotton pickers and until now not one has been successful. The International Harvester Company says the Rust brothers' device is just another failure—and they ought to know for they have a picker on which they have spent millions of dollars—and for which they have found no sales. But if experimental evidence means anything the Rust device is one apart—the first model of a truly successful picker. If it lives up to its promises the South will soon be burdened with the backs and hands of at least a million human pickers for whom there will no longer be any technical reason for existence. They are facing a ruin worse than any they have ever known—or are they?

The Rust brothers have pondered all of this. Sometimes they probably even hope their experiments will fail, so that they cannot be accused of bringing starvation to the South. They have steadily refused to sell any of the machines they make, but will license them for use. When earnings begin to be realized

For September

Million Volt X-Ray Generator, by JOHN G. TRUMP

Ferromagnetic Properties, by R. M. BOZORTH

Ambrose Swasey, A Biography, by J. J. NASSAU

Dielectrics, by CHARLES F. HILL

Solid Carbon Dioxide, by D. H. KILLEFFER.

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an organization (non-profit) will be formed to finance in some other line of activity those share-croppers displaced by the machine. It sounds very beautiful but the chances are that the plans for social alleviation will not work as well as the mechanical picker. The Rust brothers realize this but they are determined to give both a trial.

Whether this device stands or falls, or whether that social-aid scheme really works, is not nearly so important as the rise of these non-profit organizations imbued with the idea of social responsibility. Let the old-school industrialist who scoffs at such childish tricks suggest something better.

There is now an immense laboratory into which a large number of millions of dollars are being poured to demonstrate that economic injustices can be righted by the organized cooperative application of technical knowledge. That laboratory is the Tennessee Valley. "T. V. A." have been fighting initials to power companies for some months now. The claims of unfair competition from the Federal Government may all be true but the vociferousness on this point tends to hide the real objective of the Authority. In a number of ways the benefits of invention are to be brought to the people of the Valley. One of these ways is the building up of the seriously depleted soil. Along with several other chemical-engineering problems this calls for technical improvements which will permit the inexpensive production of fertilizers. Carrying the sincere hopes of many a chemical manufacturer that he would fail, Dr. Harry Curtis took the job of Chief Chemical Engineer of the Tennessee Valley Authority. Refusing to be hindered or distressed by bad wishes or politics, he has constructed a plant at Wilson Dam, Alabama, and has demonstrated by the manufacture of a great many thousands of tons of super-phosphate that it is feasible to use cheap electric power to manufacture inexpensive concentrated fertilizers. The Victor Chemical Works at Nashville, Tennessee, has for several years been making phosphoric acid from phosphate rock in a blast furnace similar to the kind used to make pig iron. Between them these two methods can and probably will revolutionize the production of phosphate fertilizers in this country.

Every technical change brings about maladjustments, more or less serious depending on the number of people involved. Much more is involved than mere unemployment or the lowering of price to consumers. New processes may destroy the capital investments of sleeping corporations; they render men and equipment obsolete; they uproot whole industries and ways of life. To date, invention and scientific discovery have kept to the black side of the ledger; they have been credits to civilization. We should like to keep them there.

No one has yet solved the problems of human obsolescence, mass motivation or technological unemployment. Unless our sociological inventiveness can show great improvement in the next 25 years we will not have made much progress no matter how pleasant and comfortable the air-conditioned lives of a few of us may be. I do not mean to imply that to get out of the woods we must have rigidly planned economy. The problem is much too complicated for that. The best plan in the world would be useless without the proper personnel, and with the proper personnel the plan, with its attending unpleasantness, is unnecessary. Education is far more important than coercion.

THE methods of science go to the root of farm problems; the methods of politics and economics, while necessary for temporary adjustments, can never do more than rearrange the surface aspect of things. One single basic scientific discovery can make all of the economic solutions to the plight of the farmer unnecessary. The man with the hoe should be nonexistent a hundred years from now.

—GEORGE R. HARRISON, "When Physics Goes Farming"
Atlantic Monthly, July, 1937

Mechanism of Disintegration of Liquid Jets

By P. H. SCHWEITZER
The Pennsylvania State College
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LIQUID sprays have extended applications. Paint sprayers, plant sprayers, atomizers, carburetors, Diesel injectors, oil burner injectors are a few of them. In these cases, disintegration of the jet is sought and promoted by pressure, swirl, turbulence and other means. In other cases, like a fire hose spray, quick disintegration is undesirable and averted. Why does a jet break up into droplets? What are the conditions under which it breaks up? What factors control "the break-up distance" and the droplet sizes?

Numerous attempts have been made to develop a spray theory but none of those offered so far is complete. It is the purpose of the present paper to help clarify and extend the picture of the mechanism of jet disintegration.

Rayleigh[1] investigated the collapse of a round cylindrical liquid column under influence of surface tension. He found that the column is unstable if its length exceeds its circumference. R. A. Castleman, Jr.[2] applied Rayleigh's theory specifically to the atomization of liquids in an air stream, under conditions similar to those occurring in carburetors. He describes the process of atomization as follows: "A portion of the large mass is caught up (say at a point where its surface is ruffled) by the air stream and, being anchored at the other end, is drawn out into a fine ligament. This ligament is quickly cut off by the rapid growth of a dent in its surface, and the detached mass, being quite small, is swiftly drawn up into a spherical drop. The higher the air speed, the finer the ligaments, the shorter their lives, and the smaller the drops formed, within limits." Castleman refers to pressure injection as follows: "It is found that when liquid is forced under very high pressure into still air it is finely atomized. As the high injection pressure merely gives a high initial velocity to the injected liquid, it is seen that this case also is similar to air-stream atomization. The fast moving liquid loses ligaments to the still air in the same way that the fast moving air drags ligaments from the quiescent liquid." In this analysis, the disintegration of a liquid spray is controlled by the surface tension of the liquid, its velocity relative to the surrounding air and the density of that air.

Rayleigh's analysis on which Castleman's computations are based is probably not applicable to pressure injection because it refers to a nonviscous liquid which is assumed to have a velocity potential. Under pressure, the liquid flows through an orifice with considerable velocity. Laminar flow of a nonviscous liquid through a pipe or orifice is nonstable and actually never occurs because the smallest disturbance changes it into a turbulent flow. The less viscous the liquid is, the readier it becomes turbulent. For a turbulent liquid the assumption of a velocity potential is not permissible. Therefore, for conditions such as we encounter in pressure injection, the Rayleigh theory is not applicable. It can be used successfully, however, as was done by Castleman, for the description of drop formation of liquid columns at rest or in slow motion as in carburetors, pneumatic sprayers and perhaps in air injection Diesel engines.

Triebnigg[3] investigated the problem from the standpoint of Diesel injection. He assumed that the breaking up of the spray is caused by the combined action upon the free end of the liquid jet of two forces: air resistance and surface tension. Upon this assumption he built up an elaborate theory which for hydraulic injection culminated in the following two equations.

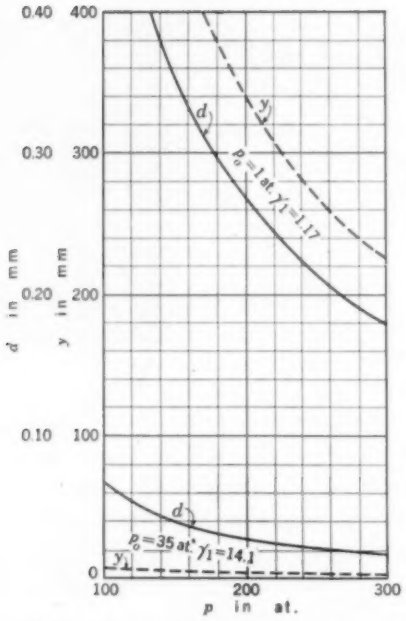


FIG. 1. Break-up distance y and globule sizes d of oil spray for different injection pressures and air pressures according to Triebnigg's theory. σ is taken as 0.003 kg/m and ψ as 0.04. The full lines refer to atmospheric chamber pressure and the dotted lines to a chamber pressure of 35 atmos. (about 500 lb. per sq. in.) (Triebnigg).

Globule diameter:

$$d=[9.2/(p_0-p_1)](\sigma/\psi)(\gamma_0/\gamma_1). \qquad (1)$$

Break-up distance:

$$y=[0.62/(p_0-p_1)](\sigma/\psi^2)(\gamma_0^2/\gamma_1^2), \qquad (2)$$

where p_0 is the fuel injection pressure, p_1 the chamber air pressure in kg/cm², γ_0 and γ_1 the specific weight of the fuel and of the air, σ the surface tension of the fuel and ψ the friction coefficient between oil and air. Both d and y are measured in meters.

Fig. 1 represents the values obtained from the equation for two conditions. The two upper curves with $p_1=1$ kg/cm² (1 atmos.) and $\gamma=1.17$ correspond to atmospheric conditions, while the two lower curves with $p_1=35$ kg/cm² (35 atmos.) and $\gamma_1=14.1$ correspond to average Diesel cylinder compression pressure and density.

The agreement between Triebnigg's formulae and experimental observations is generally unsatisfactory except for sprays injected into high pressure air, when the agreement is fair, as shown by Kluesener.[4]

Kuehn[5] was one of the first to attempt to formulate the laws of atomization and dispersion by the law of mechanical similitude.

Let μ be the coefficient of absolute viscosity, and ρ be the density of the fluid, and let v be its velocity. Then, if inertia and viscous forces alone control the disintegration of the jet, and if $\nu=\mu/\rho$ is used to designate kinematic viscosity, the globule diameter, d, and the break-up distance, y, must be:

$$d=\text{const.}\ (\nu/v) \quad \text{and} \quad y=\text{const.}\ (\nu/v), \qquad (3)$$

because assuming that $d=f(\mu, \rho, v)$ is to be represented as $\mu^x\rho^y v^z$, the only combination which gives dimensional homogeneity is

$$x=1, \quad y=-1, \quad z=-1.$$

Similarly, if inertia and surface forces alone control the disintegration of the spray, for dimensional homogeneity the globule diameter and the break-up distance must be

$$d=\text{const.}\ (\sigma/\rho)\cdot(1/v^2),$$

and

$$y=\text{const.}\ (\sigma/\rho)\cdot(1/v^2). \qquad (4)$$

If all three, inertia, viscous and capillary forces have an influence on disintegration, no practically useful formula could be obtained.

Kuehn assumed that under certain conditions the viscous forces will dominate the process while under other conditions the capillary forces will be overwhelming. With his experimental liquids, gas-oil and kerosene, the kinematic viscosities were in the proportion of 3.2 : 1 while the surface tensions were in the proportion of 1 : 1.

If viscous forces alone control the process, the jet velocities which produce equal atomization and dispersion will be with gas-oil 3.2 times those with kerosene. If capillary forces alone control the process, jet velocities which produce equal atomization and dispersion will be equal.

From his experimental data Kuehn found that at low injection pressures the ratio of the jet velocities producing equal droplet sizes were $v_{\text{gas oil}} : v_{\text{kerosene}}=2.5 : 1$ while at high injection pressures the ratio was 1.7 : 1. In no case did he find a velocity ratio of 1 for similar conditions, neither did he find that it ever was as high as 3.2. He concluded that in the process of

disintegration always a combination of forces is acting, consisting of both viscous and capillary forces. However, at lower issue velocities the process is apparently more under the dominance of the viscous forces while at higher issue velocities the capillary forces have the upper hand.

Scheubel[6] determined drop sizes of sprays of alcohol and water obtained from a carburetor jet, using spark photography for the determination. Besides the liquid, he varied the orifice size and the air velocity. To give a theoretical explanation for the results on globule diameters, he tried to apply the dimensional formula (4) in which only inertia and capillary forces are considered. The agreement was admittedly poor.

The discrepancy was ascribed to the viscosity effect. To correct for this, he proposed to consider the constant in formula (4) as a dimensionless combination of three quantities, μ, σ and v, resulting in

$$\text{const.} = \text{Const.}\ (\sigma/\mu v);$$

consequently in place of (4), he gets

$$d = \text{Const.}\ (\sigma/\mu v)(\sigma/\rho v^2). \qquad (5)$$

For practical purposes this is permissible even if in Eq. (4) it was presupposed that the effect of viscosity is nil. It would only mean that Eq. (5) is not applicable to very viscous liquids, but it may represent a good approximation for moderately viscous liquids. Scheubel shows a fair agreement between Eq. (5) and some of his experimental series but the published data do not permit a checking of his computations.

Haenlein[7] used spark photography in studying the appearance of the jet, preceding and during its disintegration. From his observations he discriminates between four different types of jet disintegration: (1) breaking into drops solely under the influence of surface tension (without the influence of air); (2) breaking into drops with the influence of air; (3) breaking up through wave formation; (4) disruption of the jet. Fig. 2 shows Haenlein's spark photographs of water jets of increasing velocity. Jet *a* has 3.1 m/sec. velocity and shows the drop formation clearly. Jet *e* has 24 m/sec. velocity and is broken up by wave formation. Jet *g* has 40 m/sec. velocity and "disruption" of the jet takes place. Figs. 3 and 4 show microphotographs of jets taken by Lee[8] breaking up (1) by rotationally similar oscillation, (2) by wave formation, (3) by complete disruption.

For the first case, Haenlein gives numerical equations based on theory which fit rather closely his observations. Indeed Haenlein found the time of disintegration, i.e., the ratio between break-up distance and issue velocity was consistently the same for the same liquid and orifice, when the issue velocity was varied between zero and about 10 m/sec. Diesel sprays, however, have velocities above 100 meter per second when a "disruption" of the jet regularly occurs. In spite of its practical importance, for this type of disintegration Haenlein offered no explanation.

The most complete theory for disintegration at low jet velocities was developed by Weber.[9] The results of his involved but very thorough mathematical analysis check remarkably with Haenlein's experimental results.

Weber first extends Rayleigh's theory to viscous liquids. Any disturbance causes the jet to assume rotationally symmetrical oscillations

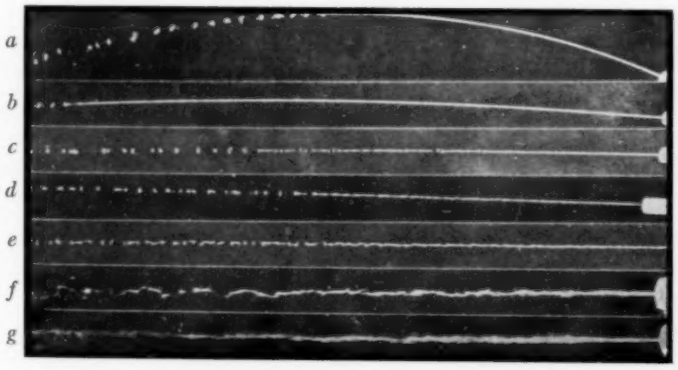


FIG. 2. Types of jet disintegration, water (Haenlein).

Glass nozzle, $d = 1$ mm,

(*a*) $v = 3.1$ m/s, drop formation without air:

(*b*) $v = 4.7$ m/s, max. break-up distance:

(*c*) $v = 7.8$ m/s, drop formation with air:

(*d*) $v = 10.0$ m/s, drop form. with incipient waves:

Brass nozzle, $d = 1.04$,

(*e*) $v = 24.0$ m/s, wave formation:

(*f*) $v = 34.0$ m/s, transition to disruption:

(*g*) $v = 40.0$ m/s, disruption.

At the nozzle 2 in. from nozzle 5 in. from nozzle

FIG. 4. Disruption (complete disintegration) of jet (Lee and Spencer).

FIG. 3. (left) Microphotographs of jet disintegration (Lee and Spencer). (a) rotationally symmetric disturbances without air influence, ×1.62. (b) rotationally symmetric disturbances with air influence, ×5. (c) wave formation, ×5.

which have a certain wave-length (see Fig. 5). If the wave-length caused by the initial disturbance is less than $L_{\min}$, then the surface forces will tend to damp out the disturbance. If L is greater than $L_{\min}$, the surface tension will tend to increase the disturbance which ultimately results in the disintegration of the jet. There is, however, a select wave-length L_{opt} which is most favorable for drop formation.

For nonviscous liquids:

$$L_{\min}=\pi d, \quad L_{\text{opt}}=\pi\sqrt{2}\cdot d, \tag{6}$$

where d is the jet diameter.

For viscous liquids:

$$L_{\min}=\pi d, \quad L_{\text{opt}}=\pi\sqrt{2}d(1+(2\mu^2/\sigma\rho d)^{\frac{1}{2}})^{\frac{1}{2}}. \tag{7}$$

The minimum wave-length is the same in both cases but the optimum (or current) wave-length will be greater with viscous liquids. For instance, for glycerin $L_{\text{opt}}=6d$, for castor oil $L_{\text{opt}}=22d$.

The time of disintegration caused by rotationally symmetric disturbances (without air influence) is calculated by Weber as

$$\tau=\text{Const.}\ ((8\rho/\sigma)^{\frac{1}{2}}d^{1.5}+(6\mu/\sigma)d). \tag{8}$$

In case of a nonviscous liquid μ is negligible and the first member will be preponderant and the time of disintegration will change as the 1.5 power of the jet diameter, while in the case of a very viscous liquid the second member will be preponderant and the time of disintegration will be in proportion to the jet diameter. Haenlein's experimental results confirm these conclusions.

Weber next examined the effect of air friction on both disintegration by drop formation (rotationally symmetric disturbances) and disintegration by wave formation (constant cross-section disturbances). For the first case he found that the effect of the air is to make both the minimum wave-length and optimum wave-length shorter. While at zero air velocity with nonviscous liquids

$$L_{\min}=3.14d \quad \text{and} \quad L_{\text{opt}}=4.44d,$$

at 15 meter per second relative air velocity

$$L_{\min}=2.2d \quad \text{and} \quad L_{\text{opt}}=2.8d.$$

The result is a shorter break-up distance.

If the air effect results in wave formation, Weber's analysis shows that a minimum velocity must exist. In the case of glycerin the minimum velocity which causes wave formation is about 20 meters per second. At this velocity the theoretical break-up distance is infinite. Increasing the velocity, first long then shorter waves appear. At 25, 30 and 35 meters per second velocities, the respective wave-lengths are 3.9, 2 and 1.3 times diameter. At the same time the break-up distance becomes shorter and shorter, rapidly at first and then more slowly.

Of the theories reviewed those which were not contradicted by experimental results refer to types of jets other than those subjected to intensive atomization. Disintegration caused by rotationally symmetrical oscillations and air action result in comparatively few large droplets. Sprays of greatest practical importance contain

millions of minute particles and have a divergent and greatly enlarged cross section. Such "disrupted" sprays were experimentally investigated by Kuehn,[5] DeJuhasz, Zahn and Schweitzer,[10] Holfelder[11] and Lee and Spencer.[8] Bird,[12, 13] Thiemann,[14] Goldthwaite,[15] and Heldt[16] suggest that the atomization of the liquid jets may be due to the turbulence of the liquid. It is along this line that further information was sought. While no complete theory is offered, the observations to be discussed suggest the following mental picture for the mechanism of spray formation.

Hydraulic Turbulence in Orifices

The jet ordinarily emerges from the spray orifice in either laminar or turbulent state. Because of the close connection which exists between the state of flow and the subsequent atomization and dispersion, it will be helpful to clarify the ideas regarding hydraulic turbulence in the light of up-to-date knowledge.

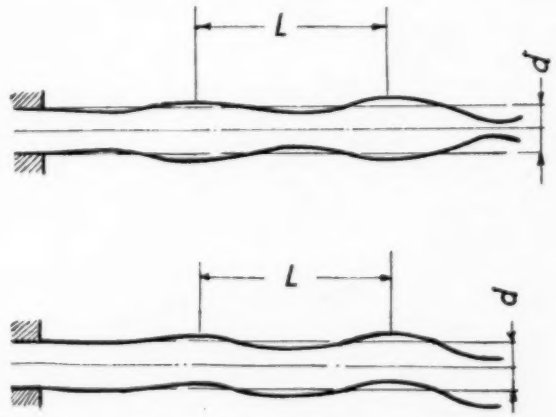


FIG. 5. Above: Jet with rotationally symmetric disturbance. Below: Jet disturbance causing wave formation.

When the liquid particles flow in streams parallel to each other and to the axis of the tube, the flow is laminar. When the paths of the liquid particles cross each other in a more or less disorderly manner, the particles having varying transverse velocity components, the flow is turbulent. In a short tube an intermediate state also exists when one part of the flow (near the periphery) is laminar and the other part (near the center) is turbulent.

If the velocity of flow in a long tube is decreased below the "critical" value a change from turbulent to laminar flow takes place abruptly. In a short tube or orifice the change takes place gradually and is influenced by a number of factors.

Turbulent flow is promoted by high flow velocity, large tube size, curvature of the tube, divergence of the tube, rapid changes in direction and cross-sectional area of the tube. Laminar flow is promoted by high liquid viscosity, laminar approach, rounded entrance to the tube, slight convergence of the tube, absence of curvature and disturbances.

Irrespective of the length of the tube an originally turbulent flow will remain turbulent, if its Reynolds number $R=vd/\nu$ is greater than the critical Reynolds number. Conversely an originally laminar flow will remain laminar if R is lower than that number.

If the flow at the entrance is turbulent but its Reynolds number in the tube is lower than the critical, the flow will turn purely laminar if the tube is straight, reasonably smooth and *sufficiently long*. If the flow at the entry of the tube is laminar but its Reynolds number is above the critical, it is hard to predict the character of the ensuing flow. If the entry is smooth and rounded and the tube free from disturbances and irregularities, the flow will remain laminar even at Reynolds numbers as high as 15,000.*

In a complete absence of all disturbances, a laminar flow probably never turns turbulent, no matter how high its Reynolds number, but the slightest disturbance will ultimately cause turbulence if the Reynolds number is above the critical. The higher the Reynolds number and the greater the disturbance, the shorter the tube travel necessary for turbulence to set in.

There is a general tendency to associate turbulence with a Reynolds number higher than critical. But the critical Reynolds number is not the one above which the flow generally or in a particular case is turbulent. The flow is frequently laminar at Reynolds numbers above the critical and it may be turbulent or semi-turbulent at Reynolds numbers below the critical.

The critical Reynolds number is the one below which in a straight long cylindrical tube

* With a convergent tube of 10° cone angle Gibson (Proc. Roy. Soc. **A83**, 376 (1910)) observed laminar flow at $R=97{,}000$.

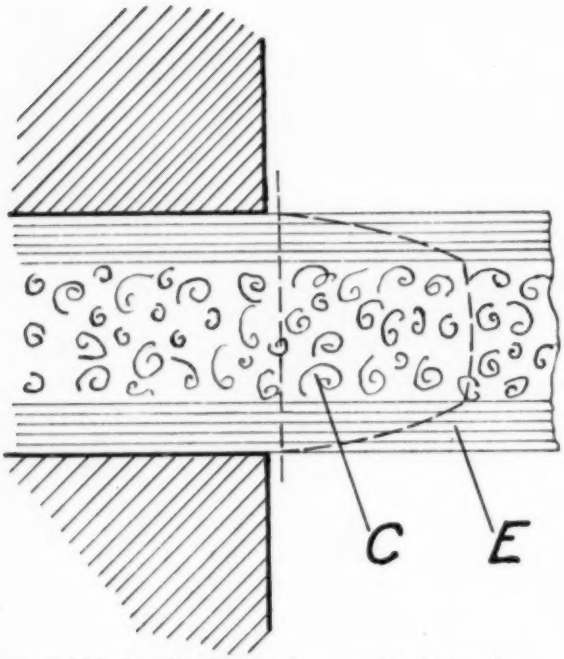


FIG. 6. Velocity distribution in a semi-turbulent jet. *C*, turbulent core, *E*, laminar envelope.

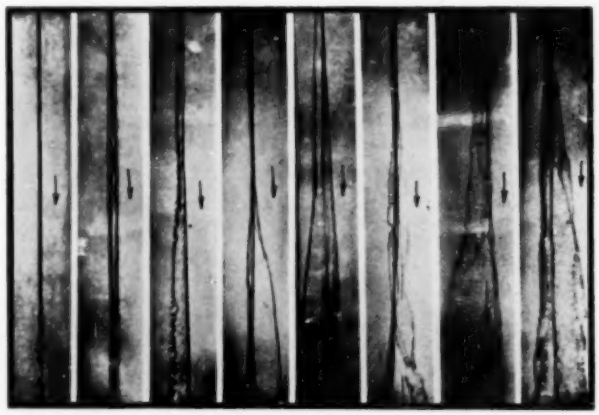
disturbances in the flow will damp out. Above the critical Reynolds number disturbances (approach-, entry-, etc.) never damp out, no matter how long the tube is. The critical Reynolds number so defined was found by Schiller[17] to be approximately 2,320.

Spray nozzles usually consist of short tubes, the length of which is not nearly enough for the flow to assume a stable condition. Under the circumstances a Reynolds number higher than critical will have a tendency toward turbulence and *vice versa* but it may take a tube travel of 60 times diameter before a stable velocity distribution is developed. The actual flow in the nozzle will be influenced considerably by the state of flow before the orifice and the disturbances in the approach and within the nozzle. The combination of these factors in addition to the Reynolds number will determine the state of turbulence in the orifice exit. For a given nozzle the influence of the nozzle factors can be considered the same; therefore the Reynolds number alone will determine the character of the flow.

Accordingly, the flow at the orifice exit may be laminar, turbulent, or semi-turbulent, the latter consisting of a turbulent core and a laminar envelope. With decreasing Reynolds number the thickness of the laminar layer increases and the turbulent inner portion decreases until it finally disappears. It is peculiar to nozzles or short tubes that the change from turbulent to laminar flow (or *vice versa*) takes place gradually rather than abruptly. The semi-turbulent state extends over a wide range of Reynolds numbers, differing only in the relative thickness of the turbulent core and laminar envelope.

Turbulence and Atomization

If the emerging jet is truly laminar, no immediate disintegration will occur. The liquid particles flow in parallel streams inside of the orifice, the layer next to the wall having zero velocity which increases in a parabolic manner approaching the tube axis. Since the wall exerts no direct influence upon either the periphery or the inside of the jet, the velocity distribution immediately past the orifice will be the same as inside of the orifice. Consequently no appreciable velocity difference exists between the air and the adjacent liquid close to the orifice, the skin of the jet being virtually stationary. It is clear that air friction cannot atomize a laminar jet as long as the velocity distribution adjacent to the skin remains parabolic, dropping to zero at the periphery. After a certain distance, however, the combined effect of air friction and surface tension gives rise to surface irregularities which lead to the disintegration of the jet.



R.N. = 1500 2400 2600 3000 3500 5000 7000 9000

FIG. 7. Fuel jets at various Reynolds numbers in vacuum (Lee and Spencer).

If the flow in the orifice is *turbulent* in its entire cross section, the orifice wall is bombarded by liquid particles having radial velocity com-

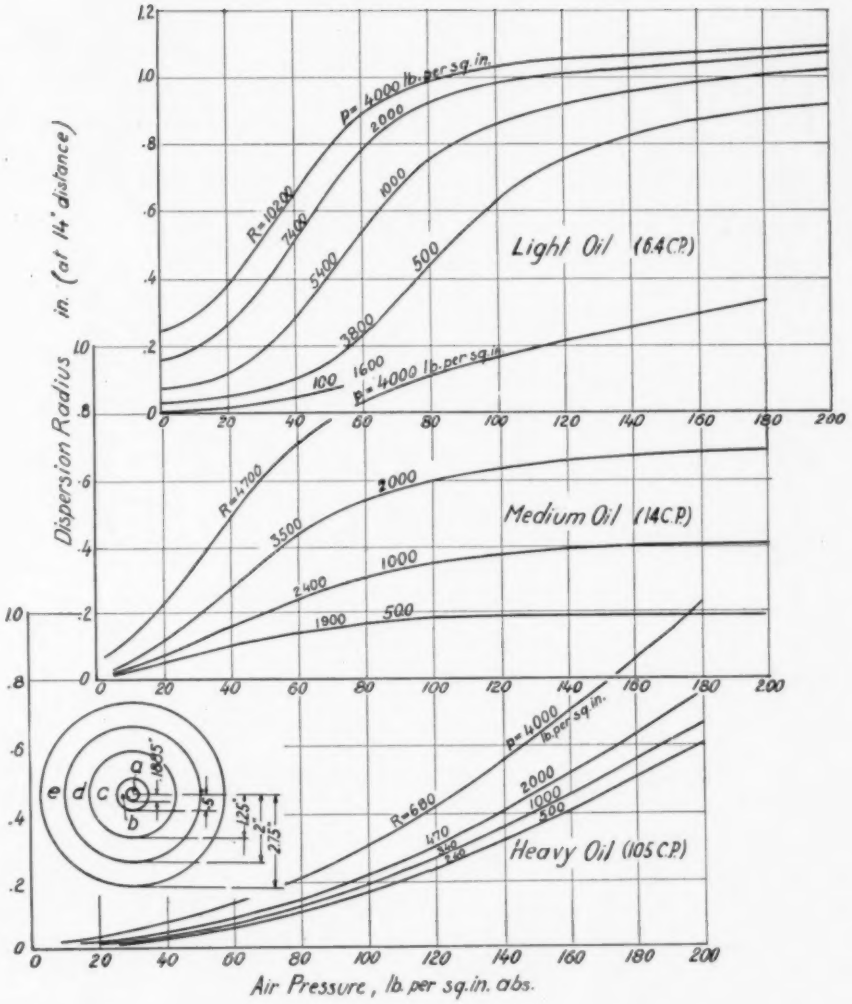


FIG. 8. Dispersion radius or the radius of greatest deposit at 14 in. distance with three different oils at varying oil and air pressure. The oil pressure is indicated on each curve and also the corresponding Reynolds number. The insert shows the arrangement of the reception rings.

ponents. As soon as the restraint imposed by the orifice wall ceases, such particles are only kept in bounds by the surface film. This may soon break under the impact of radial particles and a general disruption of the jet will occur. A laminar boundary layer may retard this disintegration only for a short period if at all. Therefore disintegration due to turbulence will take place shortly after passing the nozzle. With a jet which is turbulent throughout no air friction is necessary for dispersion. It should break up even in vacuum solely under the influence of the turbulence immediately after leaving the nozzle.

If the jet is semi-turbulent, the velocity distribution next to the orifice will be as shown on Fig. 6. The laminar envelope will prevent turbulent liquid particles of the core from passing the surface. It will similarly prevent any action on the part of air friction, because no velocity difference exists between air and the surface of the jet. Therefore no disintegration will take place next to the orifice exit. However, the faster turbulent core soon will forge ahead of the laminar envelope and having no protective coat of laminar layers it will break up. As in the case of a purely laminar jet a break-up distance will precede disintegration.

Naturally, in all three cases high air friction acts in favor of disintegration. An ever-so-small surface disturbance which is always present even in a laminar jet, gives the air stream an opportunity to tear off small masses of liquid which quickly turn into globules. In a turbulent jet the bombardment of the transverse particles makes the surface uneven. A jet with more surface disturbances will expose more parts to the attack of the air and break up more readily. Therefore dispersion caused by air friction is considerably affected by the nozzle itself. It increases with relative air velocity and air density, while viscosity has no great influence. If given time, any jet will break up finally by the action of air friction alone. The longer the jet is exposed to the air, the more it becomes ruffled and finally it falls apart.

Experimental Evidence

Experiments at the Pennsylvania State College were made with liquids of various viscosities

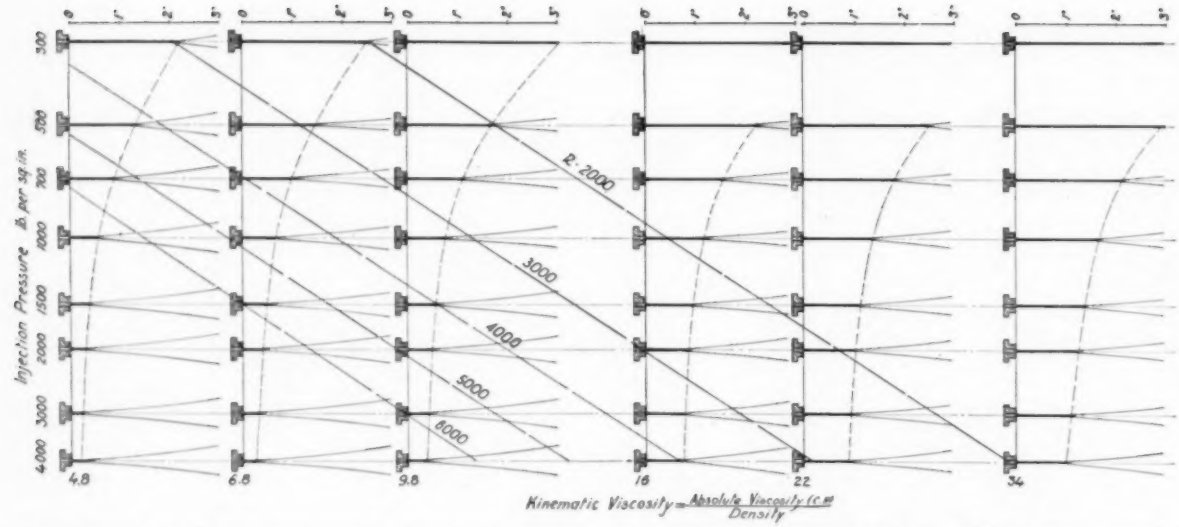


FIG. 9. Break-up distance and cone angle at various pressures and viscosities. The diagonal straight lines correspond to constant Reynolds numbers.

and surface tensions injected into a chamber filled with air of various densities. The nozzle used in most tests had a plain cylindrical orifice of 0.0135 in. and a length of 0.027 in. Break-up distance and dispersion in various distances from the nozzle were measured by calipers and also by weighing the deposits of the liquid on concentric rings of blotting paper. Subsequently experiments for the same purpose have been made by Lee[8] at the Langley Field Laboratories of the National Advisory Committee for Aeronautics by high speed photomicrography with very similar results.

Theories which attribute the disintegration of the jet solely to air friction were disproved by injecting jets into an evacuated chamber. Under favorable conditions a pronounced disintegration was observed by deposition of liquid over a wide area. Fig. 7 shows photomicrographs of sprays in vacuum. These photographs show disintegration at Reynolds numbers exceeding 2600. But only the pressure was changed between the photographs; therefore they do not prove that the disintegration in vacuum is controlled by the Reynolds number.

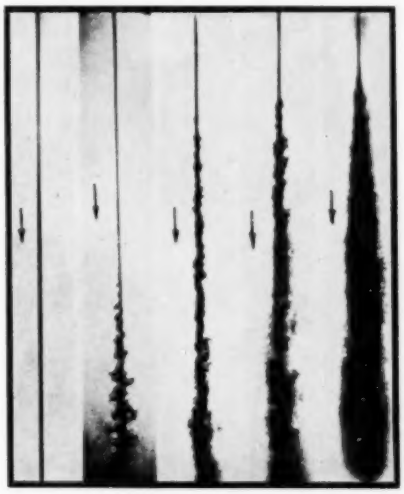
Disintegration is linked up with Reynolds number more definitely in Fig. 8. The tests were made with oils of three different viscosities, with injection pressures from 500 to 4000 lb. per sq. in. The radius of the greatest deposit at 14 in. distance was plotted against the chamber air density. Disintegration occurred whenever the radius of the greatest deposit was greater than zero. Disintegration was always observed at Reynolds numbers greater than 1600.

These observations are sufficient to hold liquid turbulence responsible for jet disintegration at least in vacuum. Naturally it is suspected of playing a decisive part even when air is present.

In Fig. 9, silhouettes of spray of various oils are shown when they are sprayed into atmospheric air under various injection pressures. The higher the viscosity the longer the break-up distance and the narrower the spray. High injection pressure has the opposite effect. In order to correlate disintegration with turbulence the spacing of the nozzles on the chart corresponds to a logarithmic scale both regarding pressure and kinematic viscosity. If the Reynolds number were the sole determining factor, sprays of nozzles lying on the same diagonal would show similar appearance. This is approximately true but not precisely. Even when Reynolds numbers are the same, the high pressure sprays have a shorter break-up distance. This shows that air friction which naturally is greater with the high velocity sprays has at least an accelerating influence on the disintegration.

From Fig. 8 it is seen that disintegration gained in intensity when the chamber air pressure was raised. Lee's microphotographs (Fig. 10) show clearly that disintegration not only

was accelerated by the dense air but was made more complete. In fact, atomization, in the sense of breaking up of the spray in millions of minute particles, could not be obtained without air friction and Fig. 7 supports well Castleman's ligament theory for this last phase of the disintegration. But to make air friction effective turbulence is essential because a completely laminar jet has a non-moving skin when it leaves the nozzle. Therefore the relative air velocity is zero. This prevents jets of high viscosity from disintegrating promptly after leaving the nozzle. With laminar jets a considerable break-up distance could not be avoided.



0.00013 1 4.4 7.8 14.5 atmos.

FIG. 10. Effect of air density on fuel jets, 0.0013, 1, 4.4, 7.8 and 14.5 atmosphere (Lee and Spencer).

Thus of the liquid properties, viscosity is recognized as having the decisive influence on jet disintegration. The effect of surface tension was found to be minor at least with high pressure sprays. At low injection pressure the surface tension was found to have a greater effect with the use of rough-walled nozzles instead of smooth nozzles. With a rough nozzle a reduction of the surface tension caused a rapid decrease of the break-up distance, while with smooth nozzle the effect was indistinct. The surface tension varied from 22 to 72 c.g.s. units in these tests while the change in viscosity was negligible. This points to the influence the nozzle construction has on the jet disintegration. Under otherwise similar conditions long smooth-walled orifices delay disintegration while rough-walled orifices with turbulences promoting shape accelerate it. Such an effect is frequently produced by imparting to the jet a rotary motion.

References

1. James Clerk Maxwell and Lord Rayleigh, "Capillary Action," *Encyclopedia Brittannica*, XI Ed., Vol. V, pp. 256–275.
2. R. A. Castleman, Jr., "The Mechanism of the Atomization of Liquids," Nat. Bur. Stand. J. Research, **7**, 269–376 (1931).
3. H. Triebnigg, *The Pneumatic and Hydraulic Injection in Diesel Engines* (Julius Springer, Berlin, 1925).
4. O. Kluesener, *Zum Einspritzvorgang in der Kompressorlosen Dieselmaschine*, V.D.I. Zeits. **77**, 171 (1933).
5. R. Kuehn, "Atomization of Liquid Fuels," Der Motorwagen, Berlin, July 10, 20; Oct. 10, 20; Nov. 30; Dec. 30, 1924. Jan. 20; Feb. 10, 1925. (N.A.C.A., T.M. 329, 330, 331.)
6. F. N. Scheubel, "Atomization in Carburetors," *Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt*, 1927. (N.A.C.A., T.M. 644.)
7. A. Haenlein, "Ueber den Zerfall eines Fluessigkeitstrahles" (The disintegration of a liquid jet), Forschung, **2**, 139–149 (1931). (N.A.C.A., T.M. 659.)
8. Dana W. Lee and Robert C. Spencer, "Photomicrographic Studies of Fuel Sprays," N.A.C.A. Report No. 454, 1933.
9. C. Weber, "Zum Zerfall cines Fluessigkeitsstrahles" (Disintegration of liquid jets), Zeits. f. angewandte Math. und Mech. **11**, 136–154 (1931).
10. Kalman J. De Juhasz, O. F. Zahn and P. H. Schweitzer, The Pennsylvania State College, Engineering Experiment Station Bulletin No. 40 (1932).
11. Otto Holfelder, "Zur Strahzerstanbung ber Dieselmotoren," Forschung **3**, 229–240 (1932).
12. A. L. Bird, "Experiments on Oil Jets and Their Ignition," Proc. I.M.E. **2**, 955–995 (1926).
13. A. L. Bird, "Some Characteristics of Nozzles and Sprays for Oil Engines," Transactions of Second World Power Conference, Berlin, 1930, Publ. V.D.I. Verlag, pp. 260–270.
14. A. E. Thiemann, "Fahrzeug-Dieselmotoren" (Automotive Diesel engines) (Publ. Rich. Carl Schmidt & Co., Berlin, 1929).
15. J. L. Goldthwaite, "High Speed Oil Engine Pumps and Injection Valves," Proceedings of the Third Oil Power Conference, 1929, The Pennsylvania State College Bulletin, Tech. Bull. 8.
16. P. M. Heldt, *High Speed Diesel Engines* (1932), pp. 74–75.
17. L. Schiller, "Untersuchungen ueber laminare und turbulente Strömung," V.D.I. Forschungsarbeiten, Vol. 248, 1922.

The Physicist and the Incandescent Lamp*

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I. What is a Physicist?

THE making of incandescent lamps is not one of the fields that the physicist has neglected, nor is it one of the fields that has neglected the physicist. For example, the Lamp Development Laboratory at Cleveland, which is the center of the research and development for the General Electric Incandescent Lamp Manufacturing Department, employs about 50 engineers and scientists who are working on lamp problems. In this group there are, by training, 6 chemists, 2 physical chemists, 22 electrical engineers, 2 general college graduates, 10 physicists and 7 that have worked their way up to the positions of lamp engineers, or assistants to lamp engineers, by the route of mechanics, glass blowers, etc. Among these fifty there are six women.

Now, just what is a physicist? I would class as a physicist a person who raises questions as to the cause of the various phenomena that are occurring around us and who is also interested in discovering some of the answers. Some will say that he has chosen too wide a field and that he should limit himself to a study of the behavior of the materials, and their parts, which make up this universe.

I wish I could tell you what makes a good physicist for the lamp industry, but I cannot. However, I think I can write down two or three qualifications that we would deem necessary for a physicist in our laboratory. In the first place he must know physics, not as book knowledge, but in such a way that he can think in physical terms. Secondly, he must be able to perform physical experiments, that is, he must be able to use his hands in cooperation with his head. Thirdly, the man must be able to fit in with the group in which he is going to work. If a man is good enough in other respects he can be an individualist, but most of us cannot afford to pay the necessary price—we must fit in.

It is easy enough to set down the above qualifications, but how are we going to find out if the man we employ meets even these few requirements? An interview will tell much but not the entire story. We must depend upon college professors for most of our information and usually they do a good job in recommending their students, both from the point of view of the student, and from that of the employer.

II. Physicists' Contributions to the Lamp Industry

While it may not be possible to outline what it takes to make a good physicist, a description of some of the problems that have been attacked by physicists in the development of the incandescent lamp may give some indication of the extent of the training necessary.

The carbon lamp.—Was Edison a physicist or an electrical engineer when he invented his carbon lamp? Many will say that he was an electrical engineer. However, very early in his work on the incandescent lamp he employed a physicist to help him. I refer to E. F. Nichols of Cornell University, who worked with Edison from about 1880 to 1881.

There is not so much interest now in the problems of the carbon lamp, although there

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must have been many problems at the time the tungsten lamp came into the field, if one is to judge by the unsolved carbon lamp problems that were passed on to the lamp laboratory. One of the first problems that Doctor Whitney attacked some 35 years ago at the then new Research Laboratory at Schenectady was a study of the carbon filament.[1] He developed a method of heat treating the carbon filament which resulted in about a 20 percent increase in efficiency over the filaments then in use. This was the last outstanding improvement in the light output of the carbon lamp to be credited to the physicist.

Ductile tungsten wire.—The first important development after the introduction of the tungsten lamp was the production of ductile tungsten by Doctor Coolidge[2] of the Research Laboratory at Schenectady. This was brought about by the cooperation of a number of men in the laboratory under the direction of Doctor Coolidge. Whether the production of ductile tungsten was a chemical or a physical development might be argued. However, after the tungsten powder is produced, all the processes involved as they are now conducted in the tungsten wire factory are physical. The physicists may claim this development even though it was carried out by a physical chemist.

The gas-filled lamp.—The next outstanding improvement, the gas-filled lamp, which came four or five years later, was also a physical development, although carried on by Langmuir,[3] a physical chemist. The idea of introducing a gas to reduce the rate of evaporation of the

Photograph of a part of a coiled coil filament, magnified about 25 or 30×.

filament was now new, but up to the time that Langmuir studied the problem, no one seemed to appreciate fully just how a gas acted to protect the filament from evaporation. He concluded that a stationary protective sheath of gas surrounds the filament. This idea led to the coiled filament. Langmuir showed that the gas loss varied with the length of the filament and inversely as the outside diameter of the coil. Thus by coiling the filament, the gas loss was greatly reduced. This same conception of a protective sheath led to the present-day coiled coil filament which promises a 10 to 15 percent increase in the efficiency of the 60-watt lamp.

FIG. 1. Photograph showing tungsten tube blackbody with pyrometer filament projected against small radial hole.

Dumet wire.—In early incandescent lamps the current entered through platinum leads sealed into the glass. Even at first platinum was quite expensive and added to the cost of the lamp, but as time went on, the price of platinum increased which made its use very expensive. A substitute was developed that consisted of a nickel iron core covered with a copper sleeve, adjusted in expansion and relative proportions so that the coefficient of expansion of the composite wire is such that the seal does not crack and therefore cause a leak.

In matching the coefficient of expansion of the glass, it became necessary to know accurately that of the composite wire. It was easy to measure the linear expansion of the wire by the usual method, but somewhat more difficult to measure the radial expansion of the small wire used for the seals. A physicist was given the problem and he solved it by using a Fabry and Perot interferometer with fused quartz plates. The two plates, separated by three small samples of the wire whose coefficient of expansion was desired, were heated in a furnace to a known temperature and a count of the fringes that shifted past the index mark on one plate enabled the calculation of the radial coefficient of the expansion of the dumet wire. In this work it was discovered[4] that the shift of the interference fringes between the upper and lower surfaces of one of the quartz plates caused by the expansion of the plate,

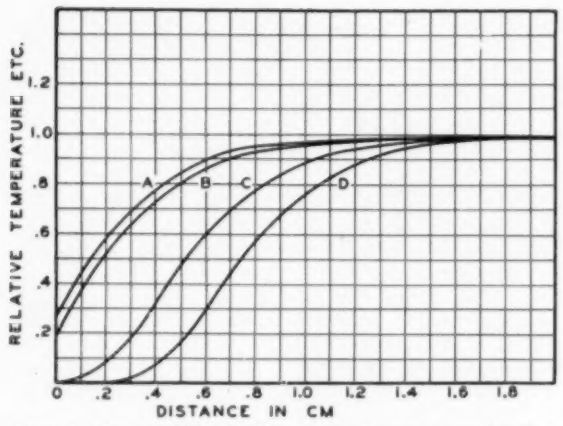

FIG. 2. Various distribution curves near a cooling junction for a long tungsten wire ($r=0.01$ cm) electrically heated in vacuum to a central maximum temperature of 2400°K. A = temperature; B = resistance; C = radiation intensity; D = brightness.

could be used as a pyrometer to measure the temperature of the furnace. Thus the operator had to count the number of fringes that passed the mark on the plate for the interference between the inner surface of the two plates and between the upper and lower surfaces of the first plate. This work was started about 20 years ago and since that time this method has been used regularly to measure both the linear and radial expansion of samples of the dumet wire that go through the factory.

True temperature of tungsten filaments.—An important characteristic of the lamp filament is its true temperature. A means of measuring this true temperature was discovered by Dr. Worthing[5] when he constructed a blackbody (Fig. 1) out of a tungsten tube with a small radial hole as the opening into the blackbody. Observations on the blackbody opening gave the true temperature and observations on the tungsten near the hole gave the radiating characteristics of the tungsten. In this manner the emissivity of tungsten for red ($\lambda=665\text{m}\mu$) and for the blue ($\lambda=467\text{m}\mu$) radiation was measured. From the values thus obtained for the red radiation, he was able to calculate the true temperature scale for tungsten for the average condition usually found in incandescent lamps.

Temperatures of lamp parts in the exhaust furnace.—A few years ago lamp engineers had trouble when heating incandescent lamps in ovens during their exhaust. The origin of the trouble seemed to be that different parts of the lamp did not come to a uniform temperature during the time it took for the lamp to pass through the furnace. The furnace was heated electrically by coils mounted inside in such a way that the radiation from them fell upon the lamp as it was passed through the furnace. To measure the temperature reached by the different parts of the lamp as it passed through the furnace was difficult because temperature measuring devices in direct contact are very apt to change the conditions, at least as far as the temperature of the point studied is concerned. However, by imbedding in the different glass parts a very fine bright nickel wire and by measuring the change of resistance of the wire as the lamp is passed through the furnace, from previous calibration the temperature of the different parts could be determined. By this method a combination of the speed of the lamp through the furnace, an arrangement of the heater coils, and insulating materials was worked out so that the different parts of the lamp reached the desired temperature.

Vibration tests.—Incandescent lamps are often used in places where vibrations of the building or nearby machinery may affect their performance. Thus it became necessary for the lamp engineer to study the effect of vibration on lamps. Several vibration racks were constructed which consisted of lamp sockets mounted on a frame attached to a solid wall with flat stiff steel springs and caused to vibrate by a rotating shaft carrying a weight off center. By this method the engineer attempted to control both the amplitude and period of the vibration. It was noticed that two racks made as nearly alike as possible and caused to vibrate with exactly the same speed of the rotation of the shaft and with exactly the same counter weight similarly placed, gave markedly different results as shown by the life of the lamps burned on these racks. It was also noticed that lamps on the different parts of the racks performed in a different manner.

A physicist was asked to make an investigation. He suspected that there were upper harmonics present in the vibration which were causing trouble. High speed moving pictures of pointers held at different positions on the two racks proved that harmonics were present and quite different at different positions.

End loss.—Heat is conducted away from filaments by their leads and supports producing what is called end loss, the amount of which has been investigated by several methods. One of these was to measure the temperature of the filament at different distances from the leads and supports and to plot the temperature as a function of length. Temperature variations were converted into relative light emissions,[6] resistances, etc. from known characteristics of the tungsten filament. From these data it is possible to calculate the end loss for various conditions.

It is difficult to measure the amount of end loss for very low temperatures (i.e. 300 to 400° above room temperature) because the cooling of the filament due to this heat loss extends so far along the filament that it requires a very long filament to insure that any part of it is at uniform temperature. This difficulty was overcome[7] by putting the base of the lamp in a furnace and heating the furnace to the same temperature as the main part of the filament, thus insuring that there would be no conduction of the heat to or from the part of the filament that was being investigated.

Energy loss from the lamp bulb.—The amount of energy dissipated by the bulb of a 115 v, 500 w incandescent lamp was measured as follows. The average temperature of the bulb with the filament at normal temperature was determined by using very fine bright thermojunction attached to different parts of the bulb. A similar bulb was then silvered on the inside with a coat so heavy that no radiation could get through. Then a filament was mounted in the bulb in the usual manner and this filament operated at such an input that the bulb reached the same average temperature as before. In this case the total input had to be dissipated by the bulb (neglecting base loss). It required about 94.5 watts input into the filament to bring the bulb to this same average temperature. The bulb was then given a good coat of silver on the outside and the filament again operated at such an input that this bulb reached the same average temperature as before. In this case it required 41.5 watts to bring the bulb to the same average temperature as before. From these figures it is seen that the bulb dissipates about 18.5 percent of the input energy when operated normally and that about 8.3 percent of the input is dissipated by conduction and convection of the air since with the bulb brightly silvered there is practically no radiation from the bulb. This leaves about 10 percent of the input to be radiated by the bulb.

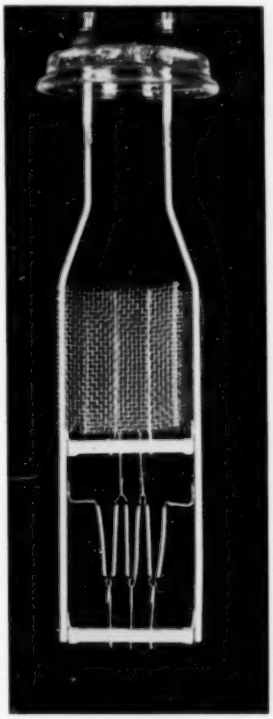

FIG. 3. Photograph of mount of new 1000-watt, 115-volt lamp showing screen to trap tungsten vapor.

Lamp blackening.—A bane of the lamp engineer's existence is the blackening of the bulb caused by the evaporated tungsten. This blackening is harmful from two standpoints. It reduces the transmission of the bulb and thus cuts down the light intensity, but if the bulb is allowed to become too black, it absorbs so much of the radiation and becomes so hot that it may fail at this point. Many attempts have been made to reduce this blackening, and just recently it was found[8] that if a screen were placed just above the filament so that the gas within the lamp bulb had to pass through this screen, most of the tungsten vapor was deposited on the screen and this very greatly reduced the blackening of the bulb. This resulted in several percent increase of the average lumen output of the incandescent lamp.

Bipost lamps.—When large lamps, such as 10, 30, and 50 kva lamps began to be made, it was found impractical to use the usual seal through glass for two reasons.[9] In the first place, with the metals then used for making the seals it was practically impossible to seal a wire through the glass and get a good seal, i.e., one that would stand up, with a conductor large enough to carry 100 to 400 amperes. The engineers would probably have found a way to do even this if there had not been another difficulty to overcome. The filament and its supports for these large lamps are so heavy that they cannot safely be supported by the glass stem. Another method

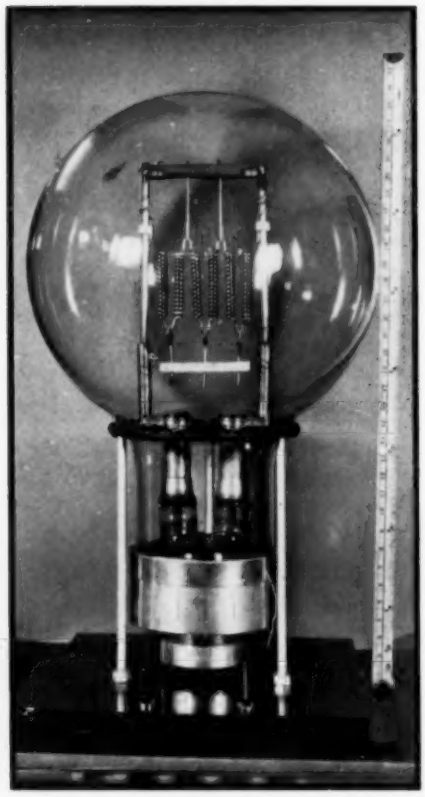

FIG. 4. Picture of 50 kva lamp showing form of first Housekeeper seal used.

had to be developed. The use of the Housekeeper copper-to-glass seal solved both problems. For these large lamps the supporting process is reversed (Fig. 3). The copper-to-glass seal carries the weight of the bulb and a copper or nickel rod straight through the seal carries the filament and its mount. Thus, the seal joint has to carry the bulb instead of the bulb carrying the filament and its support. This construction has another advantage in that it is very easy to fix the relative position of the base contacts and the filament. The way the copper-to-glass seal was first used is shown in Fig. 4 which is a picture of a 50 kva lamp.

The next step, now that it has been taken,[10] is obvious. Reverse the seal and use the copper part for a bipost base as shown in Fig. 5. This copper-to-glass seal is all that is desired for the very large lamps, but for smaller lamps of this type, that is, 115 volt, 1000 watt lamps, the copper-to-glass seal is not so satisfactory because if the coper thimble is made small enough for the small base desired, it is apt to become quite stiff and thus not very satisfactory.

Dr. H. Scott[11] was making glass seals for other purposes and developed an alloy called Fernico for sealing to certain of the hard glasses. Lamp engineers, however, wanted to use Pyrex which has a smaller coefficient of expansion than the ordinary hard glass. Considerable difficulty was experienced in attempting to seal a Fernico thimble to Pyrex. An examination of the seal with a polariscope showed that the glass had apparently cooled too rapidly as compared to the metal when the finished seal was carefully annealed in a furnace. Doctor Adams, a physical chemist, but in this instance reacting as a physicist, suggested cooling the metal parts rapidly by dipping them in water to see if the strains in the glass could be reversed. When this was done, an examination with a polariscope showed strains reversed which indicated that the metal had cooled too rapidly. Now it was only necessary to find some way of cooling the metal faster than the glass, but not as much faster as when the metal was in water. It was found that if the seal, properly heated, was allowed to cool in the open air, supported on asbestos, very satisfactory seals could be made. The strains were practically absent as shown by the polariscope. This is illustrated in Fig. 6 which shows the expansion of Fernico and Pyrex. Suppose that A represents the point where the glass is nearly solid, i.e., does not readily yield below this temperature. If the Fernico and the Pyrex sealed together are cooled uniformly, a strain due to the difference represnted by AB will result. Suppose the metal is cooled more rapidly than the glass, as when it is dipped into water so that it is at the point C when the glass nears A, a strain in the opposite direction will be set up because of the difference BC. Again, if the metal can be cooled to the point D when the glass nears the point A, there will be no resulting strain.

The ultraviolet lamp.—The introduction of ultraviolet lamps a few years ago gave the physicist some added problems. It was necessary to develop methods of measuring the ultraviolet output of the lamps.[12] In the Lamp Development Laboratory this was accomplished by using as the measuring instrument a sodium phototube

in a quartz bulb with a purple corex filter in front of the tube. This sodium phototube, thus screened, measures the ultraviolet from about 2500 to 4000A, weighted in a manner that is determined by the tube sensitivity and the transmission of the purple corex. A second measurement with the tube through a selected piece of common window glass gave a value of the weighted radiation from the lamp between about 3200A and 4000A. A knowledge of the relative radiation intensity from the lamp, a calibration of the tube, a measure of the transmission of the purple corex and the selected window glass made it possible to calculate the proper factor for correcting the difference of these readings to give the ultraviolet radiation in the erythemal region. This method is satisfactory enough so that it is still used as a method to check the lamps in the factory.

Other methods have been developed with different types of phototubes. Doctor Rentschler[13] of the Westinghouse Lamp Company developed a method for measuring the ultraviolet radiation by using a uranium phototube. This tube has a sensitivity such that when placed in a special glass bulb it measures only the erythemal radiation. The output of the cell is quite small so that a very sensitive galvanometer would be required to measure directly the current produced. Doctor

FIG. 5. Picture of bipost base.

Rentschler overcame this difficulty in a very ingenious manner. He connected (Fig. 7) a small condenser in series with a phototube and a battery. The ultraviolet radiation falling upon the tube allows a current to flow which charges the condenser. When the voltage of this condenser reaches the proper value, it is discharged through

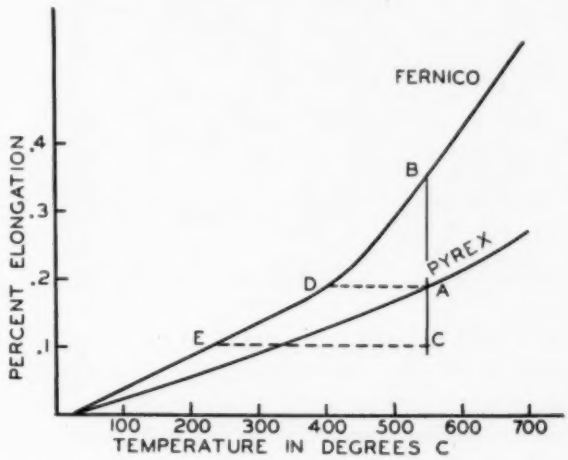

FIG. 6. Relative expansion coefficients of Fernico and Pyrex.

a special neon tube in parallel with the condenser. The discharge through the neon tube started another current from a second source of e.m.f. through the neon tube and a relay, and this relay closed another circuit which actuated a counting device. The motion of the counting device opens the second circuit through the neon tube, thus allowing it to return to a zero position ready for the second discharge. The number of discharges through this neon tube in a certain time is taken as a measure of the ultraviolet output of the lamp.

This lamp, which is a tungsten-mercury arc, is apt to become somewhat blackened during the latter part of its life because of a deposit of the evaporated tungsten from the hot electrodes. It was at first feared that this blackening would greatly reduce the ultraviolet output since the transmission of the bulb is so much reduced. Experiment showed that there was an increase of the ultraviolet radiation in the erythemal region. This was found to be due to the fact that the blackening of the bulb caused it to become hotter and thus the mercury radiation increased enough to more than overcome the loss due to the bulb blackening.

The photoflash lamp.—The photoflash lamps gave the physicist several interesting problems to deal with. It was found that if one of the

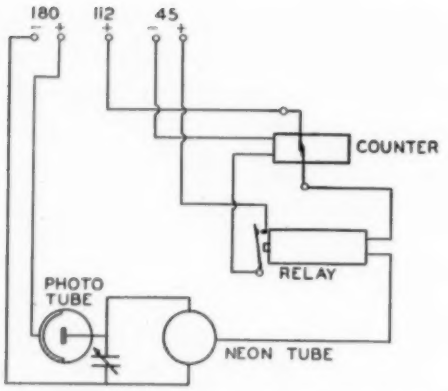

FIG. 7. Rentschler's method of measuring output of phototube.

lamps were flashed near a second lamp, the second lamp was flashed automatically. A lamp can be flashed by using a portable spark coil used to test the vacuum in a lamp. The flashing of the second lamp was found to be caused by the heat radiated by the first lamp. To measure the output of these lamps, both the maximum intensity and the total quantity of light in lumen seconds, requires some very special apparatus.[14] The time characteristics also had to be measured. These were measured by moving a photographic plate or film back of a narrow slit and having the moving plate mechanism close an electrical circuit that flashed the lamp. The light from the flashed lamp then made a trace on the moving plate from which the start of the light output, the position of the maximum output and the end of the light could be read. Thus from these traces, knowing when the lamp was started, the various time characteristics could easily be determined.

Spectroscopic studies.—A certain lamp gave trouble by failing because of a break near the center of the filament. Investigation seemed to show that these breaks came at the points where the supports touched the filament. Since the supports in this lamp were made of molybdenum, the physicist that investigated this problem decided that probably the tungsten filament was becoming contaminated with molybdenum which weakened it at these points. The question now was to test out this theory. A filament from this lamp was analyzed spectroscopically at the point where the support touched it and at a point midway between the leads and supports, with a concave grating with 15,000 lines per inch and a focal length of 21 feet.

The spectrum of the tungsten filament midway between the lead and the supports showed very pure tungsten, while the spectrum of the tungsten where the molybdenum lead was touching it showed a considerable amount of molybdenum in the tungsten wire. Of course, the solution of this difficulty was to make the supports out of tungsten rather than molybdenum.

The fluorescent lamp.—One of the most interesting developments of the past few years is the fluorescent lamp. One type of this lamp contains a small amount of mercury so that from the current through the lamp and the resulting temperature, a low pressure mercury arc results. For this type of arc, the greater part of the energy is in the resonance line 2537A. A particular fluorescent powder is painted on the inside of the tube which is about 2 cm in diameter and about 40 to 50 cm long. The mercury arc consumes about 15 watts and the resulting short wave-length radiation causes the powder to fluoresce so that the lamp has a brightness of about 0.3 candle per cm^2. Doctor Barnes of the Lamp Development Laboratory measured the intensity of the mercury radiation for the different lines and also the intensity of the radiation from the fluorescent powder for certain experimental lamps. The results for a certain green fluorescent lamp are shown in Fig. 8. The input for other sources of ultraviolet radiation, as well as the output for different types of fluorescent material

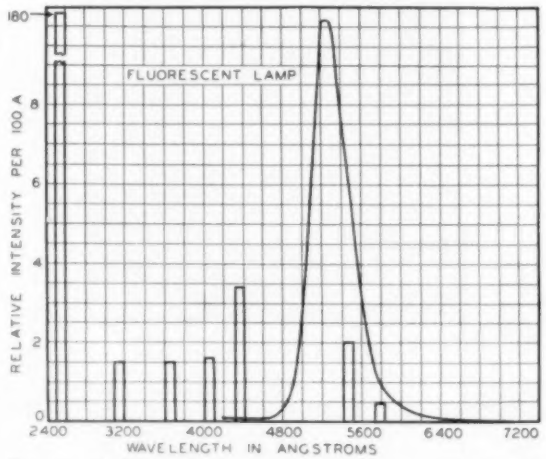

FIG. 8. Radiation from fluorescent lamp. Blocks show radiation from low pressure mercury arc and curve that of fluorescent powder.

was also measured. The results have been used as the basis for further work by the development engineer in charge of this work.

III. The Future

The lamp engineer is striving to make the best lamp possible for the use for which it is intended. The physicist is helping with suggestions for improvement and is also working on methods of measuring the output of these lamps so as to be sure that we know accurately what the output is.

The question may be asked, "Is there progress being made in this field?" Mr. Merrill, one of our commercial engineers, prepared a set of curves that show that the progress over the last 15 years is quite satisfactory. Starting with the year 1921, he figured the cost of one million lumen hours of light as obtained from the various incandescent lamps in use each year since that time and plotted the cost for each year. Mr. Merrill has also calculated the reduction in the cost of light to the customer over the past 15 years; first, because of the reduction in the cost of electrical energy; second, the saving to the customer caused by a reduction in price of the lamp; and third, the saving to the customer on account of the fact that the engineer has made several improvements in the lamps during the past 15 years resulting in increased efficiency. Fig. 9 shows the trend for the 115 volt, 60 watt lamp during the past 15 years. I can promise you definitely that starting soon there will be a break in this curve downward, that is, the cost to the customer will be less, because the efficiency of this lamp will be markedly increased with the introduction of the coiled coil filament and there will also undoubtedly be an additional saving on account of the reduction in the price of electrical energy.

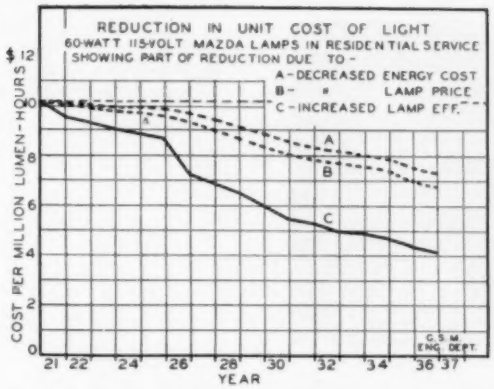

FIG. 9. Reduction in cost of tungsten incandescent light from 60-watt, 115-volt lamp for the past 15 years.

References

1. *History of the Incandescent Lamp*, Howell and Schroeder (1927), p. 84.
2. J.A.I.E.E. **29**, 961 (1910).
3. J.A.I.E.E. **32**, 1931 (1913).
4. J. Frank. Inst. **194**, 251 (1922).
5. Phys. Rev. **10**, 377 (1917).
6. J. Frank. Inst. **194**, 597 (1922).
7. J.O.S.A. **24**, 114 (1934).
8. D. K. Wright, The Magazine of Light, p. 24, Dec. (1936).
9. Gen. Elec. Rev. **35**, 96 (1932).
10. D. K. Wright, The Magazine of Light, p. 18, Sept. (1932).
11. Tran. A.I.M.E. Inst. Metals Div. 506 (1930).
12. Phys. Rev. **36**, 1468 (1930): J.O.S.A. **21**, 29 (1931).
13. J.A.I.E.E. **49**, 113 (1930).
14. Rev. Sci. Inst. **2**, 638 (1931); **3**, 488 (1932); **5**, 216 (1934): J.O.S.A. **24**, 195 (1934).

Physics in Cold Storage

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PREVIOUS numbers of the *Journal of Applied Physics* have presented important applications of physics in a wide variety of industries. This particular paper points out some of the physical problems (in contrast to what are generally regarded as engineering problems) in the cold storage industry.

Refrigeration is generally produced by the evaporation of a liquid in a so-called evaporator, the latent heat of evaporation absorbing heat from the surroundings. To complete the cycle the vapor is condensed either by compression or by absorption and then cooled to the liquid state. Details of the various types of such continuous processes will be omitted since they involve standardized equipment, constructed upon a production basis, and properly pertain to engineering.

The evaporating liquid is generally confined in a coil termed the evaporator. The refrigerant may exist in liquid form throughout a considerable portion of the evaporator ("flooded system") so that evaporation takes place fairly uniformly throughout, or it may be largely confined to the portion of the evaporator where the liquid enters, the rest of the evaporator being filled with the cooled vapor. The flooded system produces naturally a more uniform temperature.

A cold storage room may be cooled directly by an evaporator consisting of banks of coils in the ceiling (direct expansion system). In the majority of large plants, however, the evaporator coils are immersed in a tank filled with brine. The brine is pumped either through ceiling coils in the cold storage room, or (for rooms above or only slightly below 0°C) by sending the brine through coils in a small separate "fan room" or "bunker room" provided with fans or blowers which force the cooled air into the storage room. The air in the fan enclosure may also be cooled by being sprayed with cold brine. The heat transfer problems are, therefore, from air or brine through steel pipe walls to the refrigerant or from air to drops of brine.

Unless the room is several degrees above the freezing point of water and the ceiling or bunker room pipes are of large area, the pipes will be covered with snow or ice—generally ice next the pipes and snow next the air of the room.

The fundamental equation for all these problems is, for a single medium—

$$q = kA(t_2 - t_1)/L$$

or for successive media

$$q = \Delta t/(L_1/k_1A_1 + L_2/k_2A_2 + \ldots),$$

where q represents the heat transferred per second through a medium of area, A, thickness L and thermal conductivity k. If a $2\frac{1}{2}$-inch pipe is surrounded by a 2-inch layer of snow and ice, A will evidently be very different in the snow-ice layer from that in the steel. k is given in physical tables for steel, ice and snow, and for brine and air moving at various velocities. Often the tran-

This paper is the first of a series of papers on the attainment and applications of low temperatures. The many recent improvements in experimental technique point to the field of low temperature research as an extremely fertile one for future development and application to industry. The next paper in the series will be on the manufacture and uses of solid carbon dioxide.

—THE EDITOR.

sition layers from air to snow, ice to steel and steel to refrigerant, through laminar and turbulent fluid layers to the main body of the fluid, reduce the heat transfer more than the thermal resistances of homogeneous material. The thicknesses of these layers, L, are indefinite and the same is true to a less degree of the values of k. Consequently a new coefficient $h=k/L$ is introduced which can be determined experimentally with considerable accuracy even though the values of k and L are not known.

The frosting of the cooling pipes in cold storage rooms or bunker rooms is a serious problem. It is true that the area of the pipes is increased thus presenting a greater surface to the air, but ice and snow have low thermal conductivity and h has a large value for the transition air-snow. A more serious objection to heavily frosted pipes is that by reducing the distance between the pipes the air circulation between the pipes is reduced or often annulled. Defrosting is accomplished in several ways—the most common being laborious removal of the ice and snow by scraping. If a thin film (1 mm) of the ice next the pipe is melted, the frosting will under quite gentle blows crack and drop. This film may be melted by sending through hot gas (in direct expansion systems) or warm brine (in brine systems). It may also be melted by sending an electric current through the steel pipe.

$$I^2Rt/4.187 = C(2\pi rL \times 0.1 \times 80),$$

where I = current, R = resistance of a length of pipe L and radius r (in cm), t the time in seconds to melt a thickness 0.1 cm and C represents a factor to allow for loss by conduction to refrigerant, ice, etc. For an ordinary $2\frac{1}{2}$-inch pipe, C is about 3 and a current of 3000 amperes melts a millimeter film in about 15 minutes. The objection to this method is the occasional presence of poor unions which are overheated causing leaks. Within recent years cooling units have been introduced which greatly reduce the required pipe surface by blowing air at high velocities by the coils filled with refrigerant. The pipes are necessarily well below 0°C and the sublimation vapor pressure is so low that the problem of defrosting is but little relieved. Frequently frost is eliminated by brine flowing over the pipes. This, however, reduces the humidity in the storage room owing to the reduced vapor pressure of solutions and necessitates the addition of a brine pump, frequent addition of salt to compensate for the water vapor absorbed, and a sewer connection to care for surplus solution.

To maintain a constant temperature, cold storage enclosures must be insulated. The problem is one of heat transfer similar to that discussed above. For small enclosures one of the best insulators consists of sheets of aluminum foil about 0.03 mm thick, either corrugated or mounted parallel about 1 cm apart. Heat transfer by air convection is reduced to a minimum, that by radiation and conduction to practically zero and the weight of this insulation is a very small fraction of that of any equally efficient insulator.

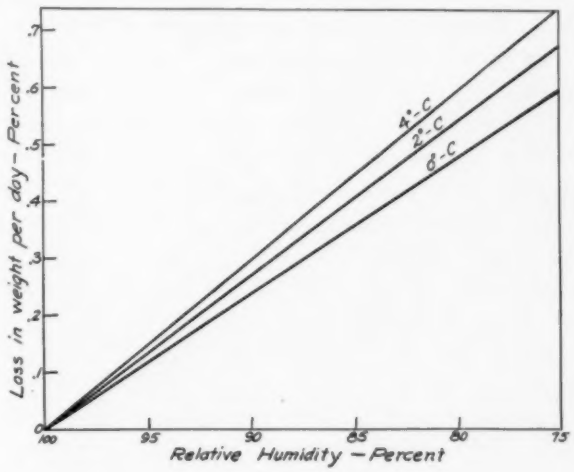


FIG. 1

In rooms maintained near 0°C (32°F) the natural convection air currents between cooling pipes in the ceiling and the warm parts of the room are always supplemented by fans unless the air is circulated by a blower which takes air from the room, cools it in a separate bunker room and returns it through outlets in ceiling ducts. Good cold storage rooms, 150 feet long and 60 feet wide, rarely show a temperature variation of 1° in different storage portions of the room or from day to day throughout the storage period of six months or more.

To prevent loss of weight of stored goods, the relative humidity in a cold storage room must be high, and to prevent deterioration of surface texture, color and taste it must often be very

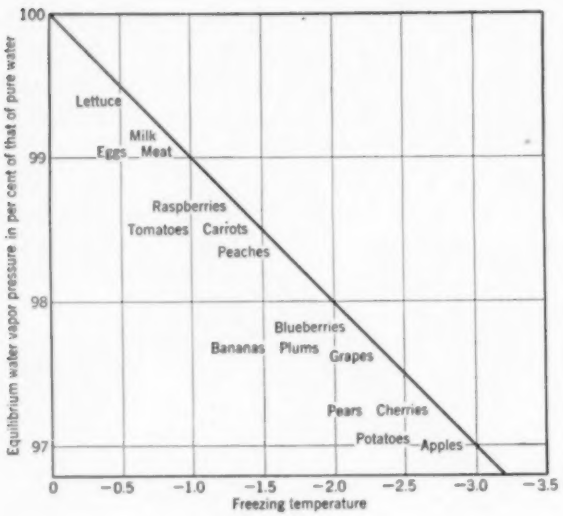


FIG. 2

high. Fig. 1[1] illustrates the loss of weight of beef at various temperatures and humidities. Although the water content of stored foods contains dissolved constituents and, therefore, has a lower vapor pressure than pure water—the difference is slight as shown in Fig. 2.[2]

Except in special cases, the air in cold storage rooms is cooled directly or indirectly by coils containing refrigerant and these coils are at a lower temperature than the air. If the coil area is relatively large the difference in temperature may be only a few degrees but, if the area is relatively small, the temperature of the coils must be many degrees below that of the rooms. In either case the air will leave the coils with a relative humidity no higher than that corresponding to the temperature of the coils and below the equilibrium vapor pressure of the food, thereby causing evaporation. In addition to the moisture traveling with the air, there is also—particularly in low temperature freezer rooms (−20°– −30°C) where there is no artificial air circulation—the direct diffusion of water vapor from the food to the cooling coils. Therefore, water vapor is commonly supplied to storage rooms containing goods especially sensitive to evaporation. If the room is cooled by air blown in from a coil room, water is introduced into the air current from atomizer jets just before the cooled air enters the duct to the storage room.

The humidity must be determined very frequently in every cooler room—i.e., in rooms carried near 0°C, and it must be known within one or two percent. Hygrometers depending upon hygroscopic sensitivity—such as hair hygrometers—are so subject to calibration alterations that only psychrometers upon the wet and dry bulb principles are employed. Although the sling psychrometer is much used, the standard instrument of a large number of the most important plants is the Fuess Assmann Aspiration psychrometer. The bulbs of this instrument are about 2 mm external diameter and of very thin glass so that they quickly reach equilibrium temperature in an air current from the room, produced by a clock work driven fan which maintains an air flow above the required minimum of 2 m per sec. for a duration of about eight minutes. Insulation against heat conduction and radiation is so complete that the thermometer

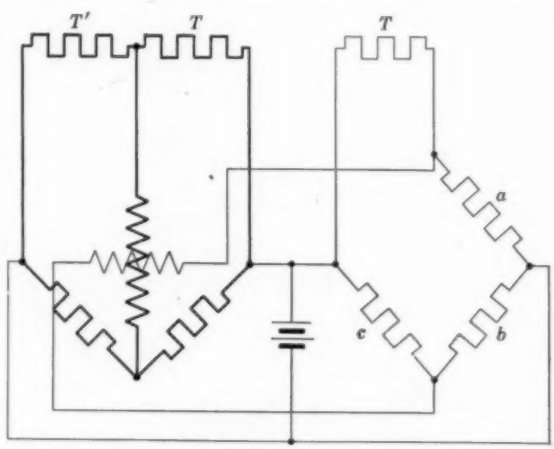


FIG. 3

readings do not change 0.1° while the thermometers are being read close to the body.

For distance observation and for recording—resistance thermometers are substituted for mercury-in-glass, a small motor and fan giving the necessary air flow by both coils. Frequently a crossed coil galvanometer is employed, with dry T and wet T' coils constituting two of the four resistances. The other coil is in the galvanometer circuit of a Wheatstone bridge with the dry coil as one of the resistances. (See Fig. 3.) The torque upon the first coil evidently depends upon the dryness of the room, that of the second upon the temperature of the room which is roughly proportional to the water content of saturated air. Thus the actual resultant deflection is roughly

proportional to the relative dryness. By proper choice of resistances in the bridges and by numbering the scale backwards, the instrument reads directly relative humidity.

If the heat capacities of the wet and dry thermometers are negligible, air motion may be dispensed with without incurring appreciable error.[3] Copper constantan thermocouples of No. 37 or even No. 40 wire, having a wet junction wrapped with fine woolen thread—the ends of which dip into a water reservoir—, give, when used with a sensitive potentiometer, very accurate results in still air. This is the best and most commonly used method today in investigations and research upon humidity problems in cold storage.

With the increasing prevalence of low temperature freezer rooms (−25°C or below) determination of the humidity at such temperatures has become important—particularly in poultry storage. Naturally the wet bulb is covered with ice rather than with liquid water. Below 0°C saturated air contains a water content corresponding to undercooled liquid water at that temperature. Since the vapor pressure above undercooled liquid water is higher than that over ice at the same temperature, the ice-covered bulb may in high humidity freezer rooms read higher than the dry bulb. In other words, water vapor is being precipitated upon the wet bulb, the latent heat freed raising its temperature. Unfortunately, this situation results in confusion in specifying low temperature humidities. The U. S. Weather Bureau wet and dry bulb tables state the humidity with reference to saturation over ice while the much more accurate German meteorological tables (used by cold storage plants employing the Fuess Assmann psychrometers) give the humidity with reference to undercooled water. For example, at −24.4°C dry bulb and −24.3° wet bulb the German tables give a humidity of 87 percent although the wet bulb is at the higher temperature. With reference to ice, the humidity is 118 percent.[4]

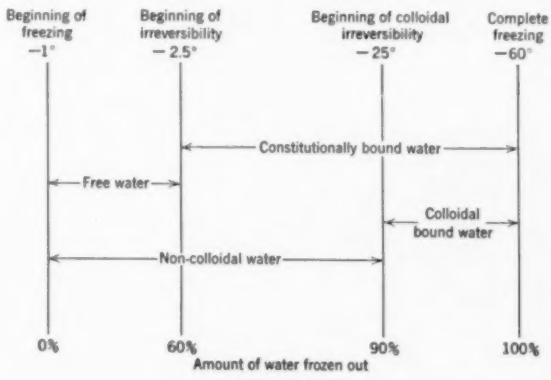


FIG. 4

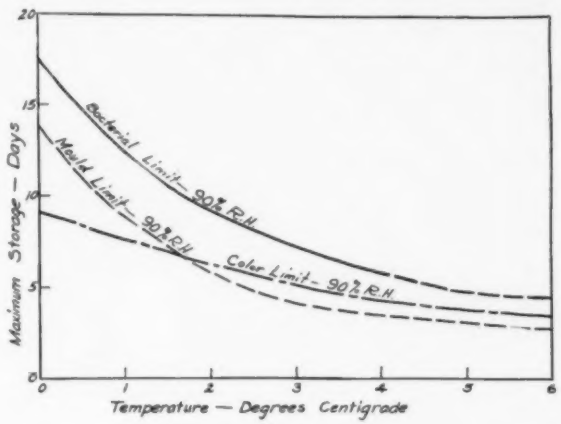


FIG. 5

Foods such as meat, poultry, butter, etc. must be frozen for prolonged storage. Fig. 4[2] illustrates the freezing of beef. Freezing commences at about −1°C. Down to −2.5° only intercellular water is frozen and when thawed out the meat is uninjured. If freezing is carried below −2.5° there are two sources of possible injury to the meat, due to intercellular water being frozen. The ice crystals formed may rupture the cells and the freezing out of ice raises the concentration of the unfrozen portion, the osmotic pressure rises and water from neighboring cells is drawn in. Crystal formation and osmotic flow require appreciable time. Therefore, if the freezing takes place sufficiently rapidly, the crystals will be too minute to break the cells and there will be little osmotic transfer of water. This is the principle of quick-freezing processes, one of the few industries which has progressed continuously throughout the depression.

The storage period of such a commodity as beef may be limited by any one of three causes—shrinkage, loss of color and bacterial or mould infection (Fig. 5). In accurate laboratory investigations the color is observed periodically with a König-Martens spectrophotometer. The initial red component of freshly killed beef is 62.5 percent. When the red component drops to 54

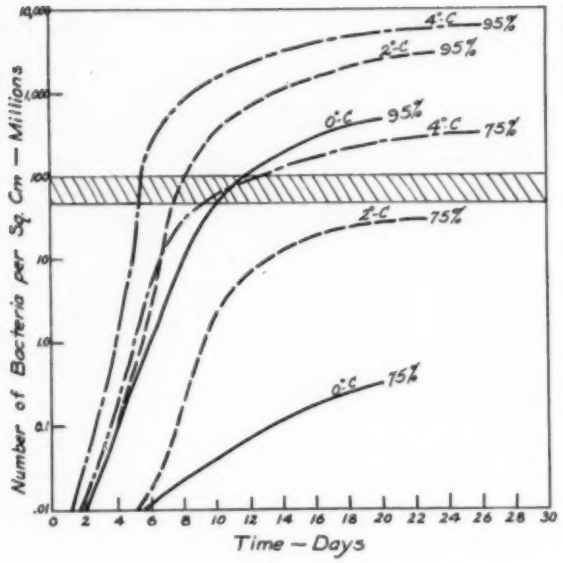


FIG. 6

percent (with corresponding increases in the blue and green) the beef has lost its full salable value. A simpler but much less accurate method of color analysis is the use of standardized color charts.

With rise in relativity humidity, the growth of bacteria (Fig. 6)[5] and mould (Fig. 7)[6] is greatly increased. (Below the shaded area the meat is saleable, above unsaleable.)

One of the oldest methods of checking bacteria and mould infection in a cold storage room is air motion. Unless the air circulation is very moderate (a few cm per sec. by the food surface) it appreciably increases the shrinkage and loss of color. If the humidity is below 80 percent,[7] air motion checks the growth of both bacteria and mould. But if it is above 80 percent, the mould growth is increased and the same is true of bacteria growth above 87 percent.[8]

The most commonly used deterrant of mould and bacteria is ozone, in concentrations of a few ten thousandths of one percent.[9] Although ozonators differ widely in design and efficiency, they all consist of concentric or parallel electrodes—the inside surface of one being covered with a glass dielectric to prevent sparking. Air is passed between the glass and the bare electrode. When an alternating current of proper potential is applied to the electrodes, a relatively silent glow discharge occurs and a portion of the oxygen ions recombine as ozone. At 60 cycles frequency a well-designed ozonator yields 50 grams of ozone per hour for each sq. meter of the bare electrode, and 0.07 gram per hour per coulomb passing through the ionized gas. At higher frequencies the yields are very much greater but the electrodes must be water cooled. The potential required depends upon the thickness of the glass and of the air. If the glass is 1 mm thick and the air 1.5 mm an alternating potential of about 9600 volts is required for maximum yield. Brass pipes from the ozonator carry the mixture of air and ozone to the blowers circulating the air in the cold storage rooms.

When the ozone comes in contact with oxidizable matter, it decomposes monomolecularly. If m is the constant rate of supply of ozone to a room, in grams per minute per m³; c, the concentration in grams per m³ of ozone t minutes after the ozone begins to enter the room; C, the final

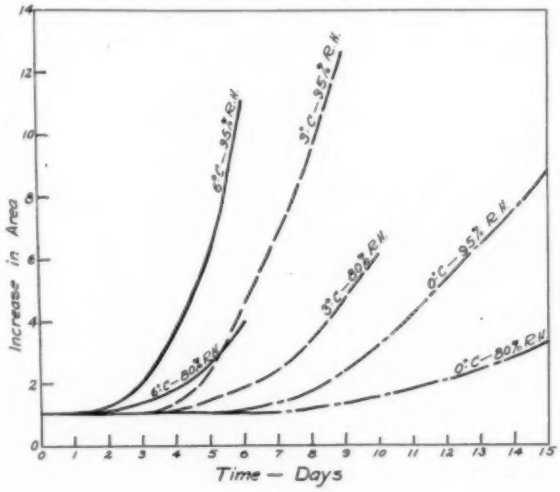


FIG. 7

equilibrium concentration; and k, the velocity or absorption constant,

$$dc/dt = m - kc, \quad C = m/k, \quad c = C(1 - e^{-kt}).^{10}$$

Therefore, if m and C are known, k can be determined. k varies from about 0.03 in egg rooms to 0.1 in meat rooms.[11]

Eggs in rooms at 31°F, a relative humidity of 88 percent and a concentration of 1.2 parts per million of ozone in the aisles, at the end of seven months, are indistinguishable in taste from eggs a few days old. Meat may be carried in rooms at 37°F and a humidity of 92 percent for six or

seven weeks without requiring any trimming on account of mould, if ozone is introduced and well distributed for two hours daily, with an equilibrium concentration of about 2.7 parts per million.

This paper has sketched a few of the applications of physics in cold storage. The opportunities for further physical research in cold storage are many. It is unfortunate that there are no laboratories in the United States which approach in quality or number of investigations the two leading laboratories of the world in this line of research—namely, the Low Temperature Research Laboratories at Cambridge, England; and especially the Refrigeration Technical Laboratory at Karlsruhe, Germany. The head of this laboratory, Professor Rudolph Plank, is today without question the leading refrigerating engineer of the world. It is interesting to note that a large portion of his theoretical and experimental contributions to the science of cold storage are primarily researches in physics. Professor Plank will take an active part in the Food Technology Conference to be held at the Massachusetts Institute of Technology next September.

References

1. Calculated from data of Tamm, Deutscher Schlachthauss Zeits. **16**, 3 (1930).
2. Compiled from Plank and Heiss, Die Wärme, No. 5, 1933; Zeits. d. v. D. Ingen. **76**, 1089 (1932).
3. Wald, Zeits. f. die gesamte Kälte Industrie **6**, 111 (1932).
4. Ewell, Refrigerating Eng. March (1934).
5. Schmid, Zeits. f. die gesamte Kälte Industrie **36**, 218–241 (1931).
6. Schwartz and Kaess, Archiv für Microbiologie **3**, 159 (1934).
7. British Food Investigation Board (1930), p. 14.
8. Loeser, Zeits. des Vereins deut. Ingenieure **17**, 8 (1934).
9. Ewell, Refrigerating Engineering, Dec. 1930, May 1932, Jan. 1935, Nov. 1935; Ice and Refrigeration, Oct. 1936 (Paper presented before International Congress of Refrigeration, The Hague, June 1936).
10. Ewell, Refrigerating Engineering, Aug. 1933.
11. Ewell, Refrigerating Engineering, Dec. 1930.

SCIENTIFIC men on an occasion of this kind regularly refer, as I have, to the social importance of their work and justify it on those grounds. We do this because we believe sincerely that this is true. We are satisfied with modest salaries because of our own personal satisfaction in work well done. This work has a permanence and lasting stability, that the work of few other professions has. I believe I speak for the vast majority of all scientific men in this Institute, in industrial laboratories, and in our Universities. Our object is not to make jobs and dividends. These are the means to an end, mere incidentals. We wish to abolish drudgery, discomfort and want from the lives of men and bring them pleasure, comfort, leisure and beauty. Often we are thwarted and our efforts perverted to other ends, but in the end we will succeed. You may bury our bodies where you will, our epitaphs are written in our scientific journals, our monuments are the industries which we build, which without our magic touch would never be. This is our statement of our pride in our work. We hope that those who work with us, capital and labor, will carve their names on these monuments with the same pride in their work that we take in ours.

HAROLD C. UREY, at dedication exercises of the new building of the Mellon Institute

The New Laboratory of the Mellon Institute of Industrial Research

The fundamental research in physics which the Mellon Institute plans to undertake marks an important step towards the desired integration of physics and chemistry. This building is destined to be the birthplace of discoveries which will increase human happiness and accelerate the course of human evolution.
—IRVING LANGMUIR

I. FORMATION OF THE INSTITUTE

THE founding of the Mellon Institute of Industrial Research was told very simply and eloquently by Mr. Andrew W. Mellon at the dedication exercises of its new laboratory in May, 1937. Quoting Mr. Mellon, "The manner in which it came about was quite unpremeditated, as those things often are. Strange as it may seem, it all goes back to a school of languages and a quite innocent desire on my part to speak French fluently enough to travel abroad in comfort—a desire, I may add, which remains unsatisfied to this day. At any rate, I called on the school for help, and they sent a young Frenchman to my house in the evenings during the summer of 1909. He was a very enthusiastic young man, and one night he brought a letter from his father in France who had made a chemical discovery, as he thought, and wanted it tested by some industry in a position to utilize the discovery commercially.

"I gave the letter to the chief chemist of the Gulf Oil Company, who reported a few days later that the supposed discovery was not of practical value, and, to prove it, gave me a book, just then published, called *The Chemistry of Commerce*, by Robert Kennedy Duncan, professor of chemistry at the University of Kansas. I read the book with interest, but the part which particularly enlisted my attention was the last chapter, in which Mr. Duncan described his plans for industrial fellowships, by means of which industry could utilize the services of qualified scientists to solve its problems, in much the same way as is being done here today.

"After pointing out the confusion and waste in manufacturing, most of which was chemical, not mechanical, he went on to say that with larger combinations of capital and a new generation of business men becoming aware of the possibilities of the new knowledge, improvements were coming and would continue to come in industry as the aid of science was invoked to solve the problems constantly arising.

"I was very much interested in these ideas of Dr. Duncan's, for as a result of all my reading and observation it seemed to me that improvement in the standard of living of the human race could come about in the future only by reason of new discoveries and inventions, just as, in the past, the steam engine and other inventions had been responsible for many improvements in the standard of living enjoyed by the average man today. It was these things, and not government or political action, that had increased production, lowered costs, raised wages, elevated the standard of living and so had brought about a greater participation of the human race in these benefits.

"It seemed to me that an institution based on Dr. Duncan's ideas could help in this advance movement; and as my brother was keenly interested in the project, we lost no time in persuading Dr. Duncan to come to Pittsburgh and organize for us here at our university this Institute of Industrial Research."

Thus, under Dr. Duncan's direction, industrial fellowships were organized in 1911. The Mellon brothers followed his experiment with great interest. They soon became convinced that the

system was sound and beneficial as a direct aid to humanity through industrial research and through training young men for productive careers in research. In 1913, in consequence of this interest and in honor of their father, Thomas Mellon, they founded the Institute and authorized Duncan to design and erect a modern laboratory. Duncan lost no time in setting this project in motion. However, in 1914 he died prior to the completion of the building, which was dedicated a year later. He was succeeded as director by Raymond F. Bacon, who served until 1921.

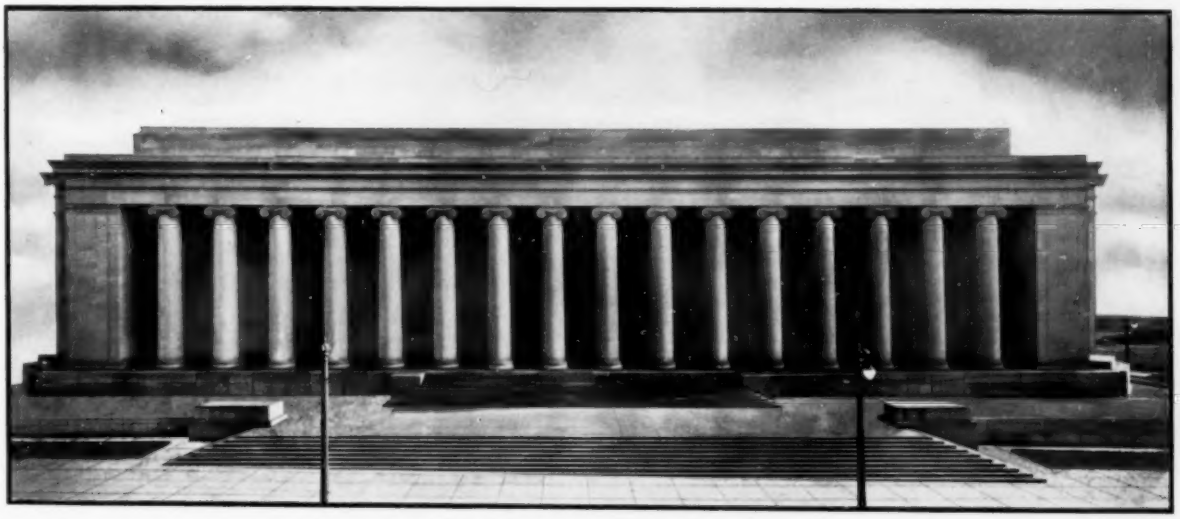
In 1916, Edward R. Weidlein, who had been a student under Duncan at Kansas and later an industrial fellow of Mellon Institute, came to the Institute as Associate Director. He became Director in 1921. On the occasion of the dedication, Richard King Mellon, the son of R. B. Mellon, declared "Acting in behalf of the founders, I have the honor to say that they have complete confidence in the future (of the Institute) under the able guidance of its present director. He has had marked success in the administration of the multiple duties that have confronted him, and keenly appreciates the tasks that are ahead of him."

There followed other encouragement by the two brothers to give the Institute greater scope. One was the establishment, in 1924, of the Department of Research in Pure Chemistry, which has accomplished remarkable results in the fields of organic chemistry and public health and has also lent valuable aid to applied research. Another was the enlargement of the Institute's facilities, made necessary by new research projects. Finally, as the outstanding gift of all, the provision was made for a new building, now occupied and dedicated May 6 to its Founders in appreciation of their generosity and humanity.

II. The New Building as an Architectural Masterpiece

Besides being a scientific workshop, the founders insisted that the new building combine simplicity of style, dignity, beauty and majesty, to inspire not only its own workers but also all those who will observe it through the years. Since the architecture of ancient Greece combines beauty with the simplicity that is appropriate to a home of science, the Grecian mode was chosen.

The needs of the Institute, as far as space is concerned, made necessary a building of about six and one-half million cubic feet, equivalent to the floor area of a very large office building. The architectural form desired dictated that it be wide in proportion to height—just the opposite from the typical skyscraper. In order to secure this low horizontal appearance, and yet provide the desired space, it was necessary to build three stories below ground level.



Classic Grecian Beauty

The front of Mellon Institute's new building at Pittsburgh, which was dedicated May 6 in honor of the founders, Andrew W. and Richard B. Mellon.

Most striking of the external features are the colonnades. To preserve their full beauty and effect, it was necessary to have all other details harmonize with the columns and to permit no

Studying the Color of Fabrics—One phase of the Institute's activity in the field of physics.

By the use of this device a fellowship in the new building of Mellon Institute is reducing to scientific accuracy the gradation of changes of colors which occur in fabrics exposed to light and weather. It is one of a group of researches aimed at finding new and higher standards for everyday commodities used by the average man and woman.

feature to overshadow them. That this has been done is evident from the illustrations. Much of the grace and sculptural quality of the facades is attributed to the fact that these columns are monoliths and thus have smooth shafts unbroken by disturbing horizontal lines. There is a beautiful accuracy in the carving of the exterior ornament. The capitals of the columns are so nearly perfect in execution that it is impossible for the eye to discern any irregularity. The jointing of the plain masonry is considered remarkable by technicians, and the columns have been set with almost mathematical precision. Many experts have expressed the opinion that the masonry of the Institute probably ranks with the finest of the world's work in stone.

III. The Interior

Because of the Institute's massive exterior, it would have been impossible to place sufficient windows in the outside walls to provide adequate light to the numerous laboratories and offices. For this reason the building was designed to include four interior courts as the main natural light sources. The building is in the form of a hollow square, wider at the front than in the rear and with center and connecting wings in the form of a cross. The outside sections of the building, which surround the hollow square, are nine stories high. The center wing, intersecting the square from front to rear, is of the same height. The cross wings, which connect the center wing with the east and west outside sections, are four stories high.

The main entrance of the Institute is from Fifth Avenue at the fourth floor level. Thus although the first floor is below ground level, most of its rooms receive light through the four interior courts. All the general service facilities and building machinery are concentrated on this floor as are the unit plants for experimental production conducted by various fellowships.

The auditorium, the principal feature of the second floor, occupies the entire space in the center wing from cross wings to rear section; it is two stories high and has a seating capacity of three hundred and fifty. This room will accommodate functions of professional nature, thus enabling the Institute to fulfill adequately one of its educational purposes. The auditorium equipment includes a theater-size screen, sound-picture projectors, a stereopticon projector, and amplifying facilities for the presentation of addresses and other programs by recordings, by radio and even by telephone.

The third floor is at street level on the west side and at the rear. Entrance from this side is primarily intended for use in connection with the auditorium. A social room is entered from one side of the entrance lobby. This room is the largest of a suite of rooms which contain space allotted to social and recreational activities in the Institute. It provides a congenial atmosphere for informal conferences and also a place for social activities of the Robert Kennedy Duncan Club, the social organization of the Institute's

members. Directly behind and connecting with this room is a large, well-appointed kitchen.

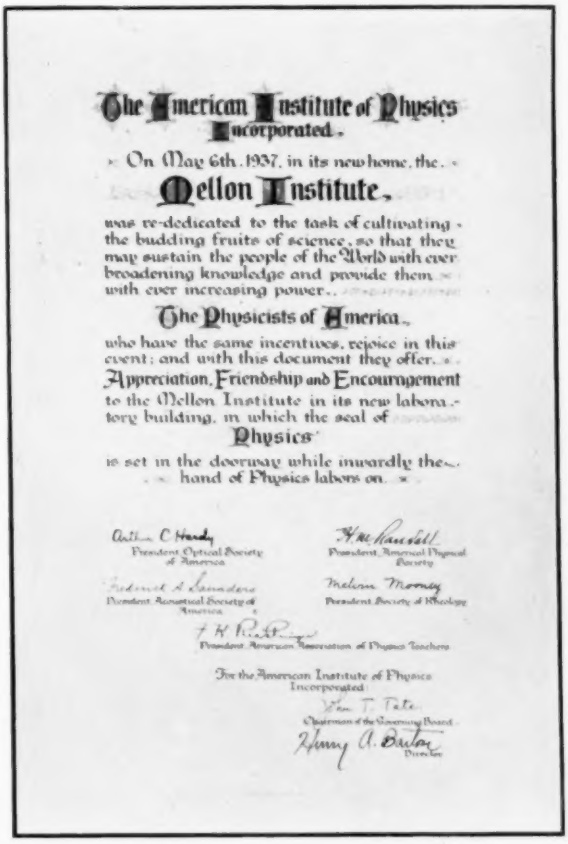
Located in the east cross wing is the building control room, in which gauges indicate the operation of various service facilities. The building heating system is controlled from this room. Adjacent to the control room is the telephone switchboard room, and beyond it is the room containing the apparatus which operates the inter-office automatic telephone system.

Seal of the American Institute of Physics as it appears on the floor of the main vestibule in the new Mellon Institute building.

The fourth floor is devoted chiefly to the administrative side of the Institute's work. The library is also on this floor and is considered the most impressive room in the Institute. Directly behind the library is the workroom where books are repaired and records maintained, and nearby is the stack room which, with present and other reserved space, will permit expansion of the Institute's collection to more than 100,000 volumes.

The fifth to eighth floors inclusive, are devoted to laboratories for scientists on the Institute's staff. Each floor has special rooms for the use of all researchers, but most of the space is devoted to laboratories of two types—small laboratories for individual workers, with offices opening into the marble corridor, and larger laboratories arranged in suites, each with an office. All laboratories face on the interior courts, as the building has been erected as a hollow square. Exceptionally large windows are provided and the courts on which they face are surfaced with glazed ivory terra cotta having high light reflectance, thus assuring plenty of daylight. Much care has been given to details of equipment of these laboratories. Wall brackets are so built that shelves may be placed at will and instantly removed. Cabinets are constructed so that a complete unit may be removed and shifted to another laboratory when desired. Furniture is made without bolts or screws—only a rubber mallet is needed to take apart the laboratory tables or to add to them.

Among other special features are the constant-temperature, constant-humidity rooms, facilities for nutritional studies, laboratories devoted to ceramic furnaces, ample rooms for experimental plants for basic production research in evolving chemical manufacturing processes, an analytical department, machine, instrument and glass-blowing shops, and x-ray and spectroscopic facilities, all available for the use of Fellows of the Institute.



The American Institute of Physics
Incorporated

On May 6th, 1937, in its new home, the

Mellon Institute,

was re-dedicated to the task of cultivating the budding fruits of science, so that they may sustain the people of the World with ever broadening knowledge and provide them with ever increasing power.

The Physicists of America,

who have the same incentives, rejoice in this event; and with this document they offer

Appreciation, Friendship and Encouragement

to the Mellon Institute in its new laboratory building, in which the seal of

Physics

is set in the doorway while inwardly the hand of Physics labors on.

Arthur C. Hardy
President Optical Society of America

H. M. Randall
President American Physical Society

Frederick A. Saunders
President Acoustical Society of America

Melvin Marsh
President Society of Rheology

F. K. Richtmyer
President American Association of Physics Teachers

For the American Institute of Physics
Incorporated

Wm. F. Tate
Chairman of the Governing Board

Henry A. Barton
Director

This, then, is the new building. Recently Dr. Weidlein declared, "More and more fundamental knowledge is to be sought through the expansion of staff and facilities in those departments dealing with research in the pure sciences. Since 1924, the Institute has maintained a department of research in pure chemistry and has contributed in an important way to that science and also to public health. It will now be able to devote investigational attention to problems in the fields of physics and biology."

High Voltage Vacuum Tube Rectifiers

Physical Factors Influencing Their Design

By M. J. GROSS and Z. J. ATLEE

Vacuum Tube Department

General Electric X-Ray Corporation

Chicago, Illinois

OF the many physical factors pertaining to vacuum tubes a few can be selected as being principally involved in recent high voltage rectifier design.

Field Currents—Electrode Spacing

Very definite minimum spacings between electrodes are found in both rectifier and x-ray tubes which cannot be reduced without erratic operation, the spacing being a function of the maximum voltage that the tube must stand (Fig. 1). This erratic operation is independent of gas pressure over a wide range and is due to field currents or so-called "cold cathode discharges."

The first indication of field currents in a rectifier may be the generation of x-rays. If the voltage is increased beyond the point where weak x-rays are detectable, erratic inverse current discharges occur, usually accompanied by voltage surging. Factors besides total inverse voltage that affect the required spacings are:

(a) *The shape of the electrodes.* Although this obviously influences the field strength, its importance is overshadowed by the following:

(b) *Microscopic surface irregularities.* Compton and Langmuir[1] have shown that small projections on a large surface give localized fields of ten to one hundred times that calculated as the average over the surface. These projections may be present in spite of careful polishing because of gas liberation and roughening of the surface during exhaust.

(c) *The kind of surfaces involved.* Again, according to Compton and Langmuir field currents occur more readily from surfaces covered with absorbed films of electropositive metals. Certainly it is true that surface films of contamination influence the required spacing.

(d) *Aging, or the past history of the surfaces.* In practically all cases it is found that a given spacing can be made to stand more voltage by operating at the voltage where cold cathode discharges are just barely obtained. Gradually this voltage can be increased. In a tube being continuously evacuated the improvement may be only temporary. In a tube thoroughly degassed and sealed off from a pumping system most of the aging is permanent. Some of the improvement may be due to elimination of surface films or to rounding off of sharp microscopic projections. Regardless of explanation it is real, and may extend the practical range of voltage operation as much as 100 percent.

M. J. GROSS

Z. J. ATLEE

Vacuum

Contrary to some belief, the actual degree of vacuum required in high voltage tubes is no greater, and may be less, than that required at low voltage. For example, a pliotron with thoriated tungsten filament operating at 2000 volts will require an appreciably higher vacuum (of the order of 0.001 micron) than a rectifier or x-ray tube having a pure tungsten filament operating at 200,000 volts. In the former case a few positive ions can bombard and destroy the thorium film while in the latter case they ordinarily do no damage until their number increases to the point of causing unstable conditions and breakdown of rectification. This limiting pressure is relatively independent of the voltage in the range of 50,000 to 500,000 volts, but is dependent upon the kind of gas present. Although five or

ten microns of helium or hydrogen may give no trouble (even in a 400,000 volt x-ray tube) a pressure in excess of one or two microns of nitrogen will generally cause breakdown of rectification.

The real vacuum problem at high voltage is to degas the various parts of the tube sufficiently so that when it is sealed off of a vacuum pumping system the gas pressure stays below the limiting value for a long time under the unfavorable conditions of electron bombardment and heating that occur in operation. Processes for degassing depend upon heat applied either in a vacuum or in a reducing atmosphere of hydrogen, and upon extreme cleanliness.

Electrostatic Mechanical Forces

The earliest forms of high voltage kenotrons[2] (Fig. 2a) were limited in voltage because at potentials of the order of 100,000 volts the electrostatic force on the mechanically weak incandescent filament had a tendency to pull it out of shape towards the anode, reducing the spacing and causing either field currents or filament breakage. Inasmuch as the mechanical force increases as the square of the field strength, it is essential at high voltages that the fragile filament be protected from distortion by some method of shielding that reduces the field strength at its surface. In x-ray tubes this is accomplished incidental to the focusing of the electron beam by placing the filament inside of a focusing cup. Most of these structures are unsuitable for rectifier use because they produce too high a space charge and concentrated heating on the anode. One practical rectifier design of cathode structure is shown in Fig. 3. The heavy spiral surrounding the filament is at practically the same potential as the filament. It is enough of a shield to take most of the voltage gradient off of the weak filament without prohibitive focusing or increase in space charge.

Design for Reproducible Voltage Drop

In most applications of high voltage rectifiers the actual voltage drop is relatively unimportant as long as it is reproducible and does not exceed several thousand volts. It would not be a significant factor in design except for the possibility at high voltage of grid action from electron charges on the insulating walls of the rectifier. The importance of this has not always been realized. In certain designs it has caused erratic voltage drop and occasionally even failure through the sequence of high drop, overheating of the anode, inverse emission, and filament destruction.

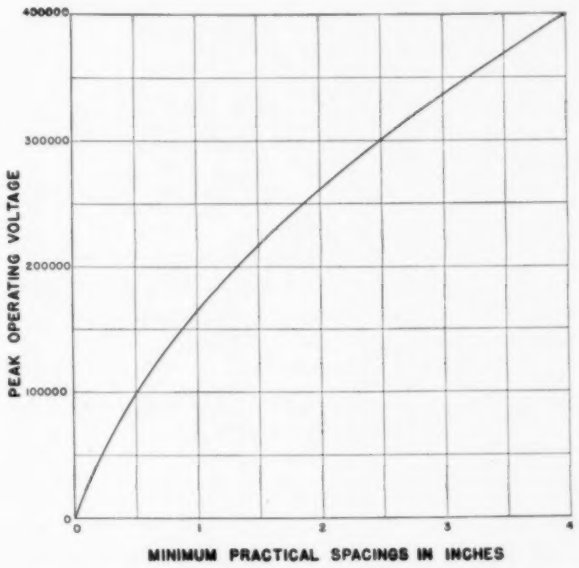


FIG. 1. Electrode spacings required to prevent erratic field currents in commercial x-ray and rectifier tubes. Data interpolated for two-inch diameter electrodes, rounded, polished and degassed. Approximately true for iron, nickel, copper, tungsten, or molybdenum materials.

The original kenotrons, Fig. 2a, were immune to this phenomenon because the cylindrical anode effectively shielded the anode-cathode space from the influence of any grid action on the glass. However, because this type was limited in voltage (see preceding section) a second type was developed, Fig. 2b, having a round disk anode located a centimeter or more from the ends of a loop filament. This solved the electrostatic pull problem by making the direction of the pull along the axis of the weak filament, rather than at right angles, but it introduced the possibility of grid action from the envelope. Rectification up to 150,000 volts was made possible, but in some cases with an erratic voltage drop as high as fifteen to twenty thousand volts. This kind of operation was reasonably satisfactory for applications such as cable testing and smoke precipitation, but not for x-ray work where a small change in voltage drop might cause

an appreciable change in r output or photographic density.

The magnitude of the grid action varied with many factors, such as the configuration of the

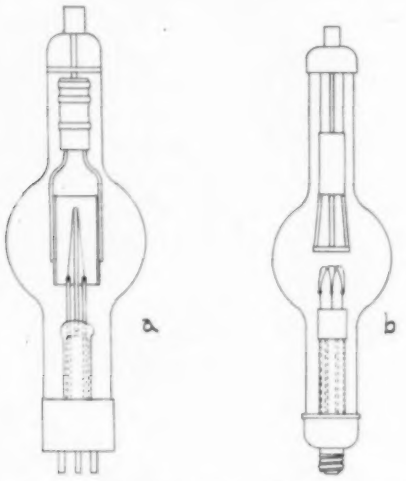


FIG. 2. Early kenotrons. (a) Cylindrical anode type, (b) end-on type.

tube, the cleanliness of the glass surface, the gas pressure, the voltage and current of operation, the circuit, and the location of surrounding objects.

Many experiments were tried in attempts to reduce the grid action to a minimum and constant value. One experiment, reasonably successful, consisted in placing a band of metal foil outside of and around the central portion of the tube and connecting it through a high resistance to either the cathode or anode terminal. The difficulties encountered in applying such methods of control emphasized the advantages of the cylindrical anode design of the kenotron in which the electrode space is shielded from electron charges on the envelope. Therefore, emphasis was directed towards redesigning this type of kenotron to overcome the limitations of cold cathode and electrostatic stress phenomena, as has been described in preceding sections, with the result that cylindrical anode tubes have been developed to successfully rectify voltages exceeding 200,000 without erratic voltage drop.

Envelope Surface Phenomena

Electron bombardment of the envelope influences design in more ways than a discussion of space charge alone would indicate. It can be responsible for complicated phenomena involving heat, secondary electron emission, fluorescence, ionizing discharges along the surface, and puncture of the envelope.[3] Under the right conditions, one or more of these may give trouble in operation. They are controlled by the envelope and electrode configuration, the material and thickness of the envelope, and the location and amount of surface films of foreign material on the envelope.

The importance of configuration is fairly obvious. For example, a configuration that allowed appreciable electron bombardment close to one end of the tube might be limited in operation by ionizing discharges along the surface of the envelope or by conduction current, heating, and gas liberation. In the small oil-immersed kenotron shown in Fig. 4 the anode is cup shaped, that is, closed at the anode end of the tube, and electrons are prevented from reaching the glass except by way of the cathode end opening.

The importance of the envelope material lies in its physical properties, such as electrical conductivity and dielectric strength. The borosilicate type of glasses, of which the Corning

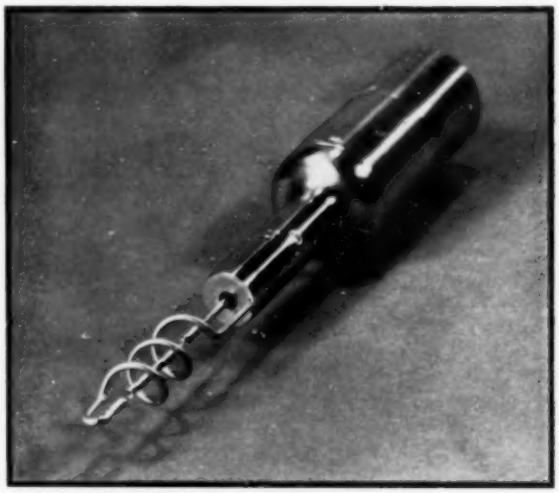


FIG. 3. Cathode structure showing an electrostatically shielded filament.

Glass Company's No. 774HR is one example, have proven very suitable. Their advantage lies in low conductivity, high dielectric strength, and high melting point, which allows degassing at 500 degrees centigrade. Splices and defects such as elongated bubbles of gas are always weak spots from the standpoint of dielectric strength

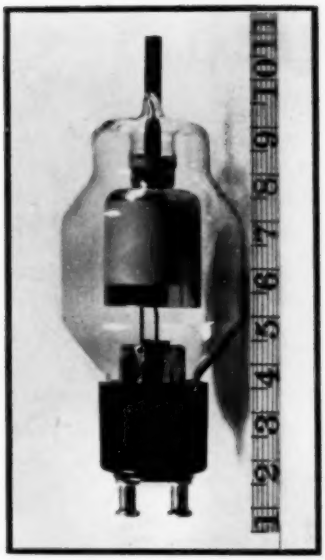


FIG. 4. Oil-immersed kenotron for intermittent duty up to 140 kilovolts peak, 500 ma.

and must be carefully controlled to avoid puncture. Small amounts of evaporated or sputtered metal on the envelopes play a more important part than is generally appreciated. Trouble may come from erratic ionizing discharges between isolated particles or over semi-conducting films and may not be serious until after a long period of operation. In general, it is impossible to prevent all foreign deposits, and configuration of the electrodes and envelope must be relied upon to prevent high electrostatic stress in regions where deposits may occur.

References

1. Karl T. Compton and Irving Langmuir, Rev. Mod. Phys. **2**, 160–171 (1930).
2. Saul Dushman, Gen. Elec. Rev. (1915).
3. W. D. Coolidge, L. E. Dempster, and H. E. Tanis, Jr., Physics **1**, 230 (1931); M. J. Gross, Am. J. Roentgenology & Radium Therapy **36**, 525 (1936).

IT is strange that the physicist was so late in coming—strange because papermaking involves so much physics. This seems to be entirely the fault of the physicist. While chemistry spread rapidly from the scientific laboratory to the industrial plant, the physicist seemed satisfied to leave the practical applications of his science in the hands of the respective branches of engineering which grew up for this purpose. This might have gone on indefinitely in the paper industry had there not developed a sudden industrial demand for photoelectric and optical instruments. No branch of engineering existed to meet this demand. Either such a branch of engineering had to be developed or the physicist himself must turn industrialist, which he did. It seems certain that he will be with us from now on and not with his efforts confined to the small field by which he entered but spread over the entire papermaking field. The well-trained physicist with a strong background in chemistry seems ideally qualified to handle the papermaking problems of the future.

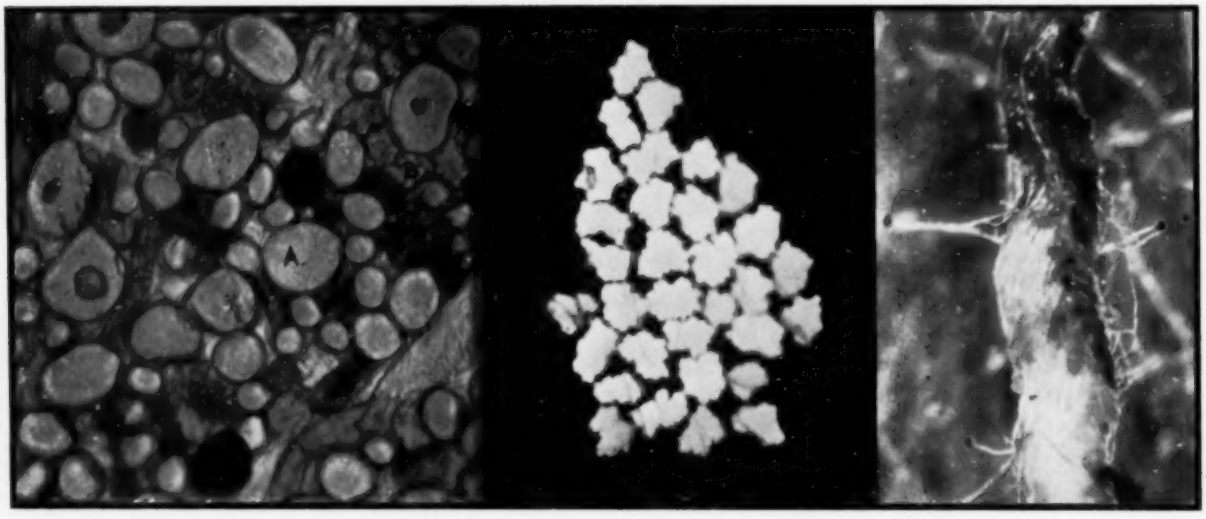
GEORGE C. MUNRO, "The Physicist and Papermaking Problems," The Paper Industry, October 1936

Textile Research at the Massachusetts Institute of Technology

By E. R. SCHWARZ
Department of Mechanical Engineering
Massachusetts Institute of Technology

TEXTILE research at the Massachusetts Institute of Technology has been developing more and more rapidly since 1917, and over the first half of this twenty-year period was centered largely in the field of simple physical testing. Working in close cooperation with the National Bureau of Standards and the American Society for Testing Materials Committee D-13, a number of test methods and machines were developed ranging from crimp testers for tire fabric yarn and airplane wing fabric, through tensile, bursting and compression testers to abrasion, water-proofness and permeability measuring instruments. A most important contribution was information as to the nature of certain factors which caused considerable variation in test results—notably temperature, relative humidity, rate of load application and machine capacity. Means by which these and other variables might either be eliminated, controlled or corrected for were developed and form a background for continuing research in this field.

Microscopical analysis of textiles was undertaken as a coordinated part of the program about 1924, and has since developed to a considerable degree. Similarly during the last ten years, researches in the field of textiles have been more and more numerous in various departments of the Institute. This has been the result largely of work made possible by the Textile Foundation,



Cross section of a portion of a yarn labeled "*100% camel hair.*" The picture shows wool fibers, bright rayon and de-lustered rayon at *A*, *B*, and *C*, respectively.

Cross section of a viscose rayon yarn.

Ultropak photomicrograph (surface illumination) of fungus growth on yarn.

the Chemical Foundation and the Massachusetts Institute of Technology Division of Industrial Cooperation.

The Textile Foundation has supported four fellowships at the Massachusetts Institute of Technology extending over the last five years. They have been concerned with the microbiology of textile fibers, the microscopical analysis of fiber structure; the measurement of the color of dyed textiles and the systematic, optical grading of wool top fineness leading toward the establishment of proposed new government standards.

The Chemical Foundation has established at the Massachusetts Institute of Technology one unit of the new Institute of Cellulose Chemistry and through the United States Institute for Textile Research has been active in the establishment of the trend of the research program of the textile laboratory. The laboratory work for the warp sizing research program of the United States Institute for Textile Research has now been going on in the textile laboratory for nearly two years and will continue.

Through the Division of Industrial Cooperation many problems involving research activities of diverse laboratories have been undertaken and have in many instances initiated independent staff or student research on aspects of problems brought up during the investigation of the major problem.

Several hundred theses, both undergraduate and graduate have been completed, and in numerous cases have been productive of important results. These, together with researches undertaken by staff members either as accessory to teaching or for the sake of the problem itself, are being continued.

Such investigations as those of Edgerton in the application of stroboscopic and high speed motion picture photography have found direct textile application. The spectrophotometric analysis of color is still another example. Further work in x-ray diffraction such as was carried out by Professor Warren on asbestos is of considerable theoretical and practical importance. Work is under way leading to more active research in the field of dye chemistry; the physics of yarn structure; the use of polarized and ultraviolet light for fiber analysis; the physical properties of fabrics, such as water-proofness, permeability to gases, resistance to abrasion, resistance to repeated stress, and the like; fiber structure problems such as molecular orientation and its effects on other properties; fiber identification, swelling and disintegration phenomena, etc.

In the future, as in the past, the program of research will be conducted in three directions. First, every effort will be made to continue so far as we may the establishment of data, machines, instruments and techniques for routine testing. Second, the laboratory will cooperate with industry for the solution of current problems. Third, investigation of new developments in science will be made to be certain that those having interest and value for textile research, pure or applied, will not be missed.

EVEN the most unimaginative and shortsighted, hard-headed, "practical" business man is forced to admit the justification for the pure research—of no preconceived practical use whatsoever in the minds of those who led in its prosecution and of all degrees of success and significance—which has been directed at the electron. For out of this research have come the following things which all can understand and appreciate: a growing business in manufacture of electronic devices which now amounts to fifty million dollars a year in America alone; a total business of some hundreds of millions of dollars a year which is made possible by these electronic devices; innumerable aids to health, safety and convenience, and an immense advance in our knowledge of the universe in which we live.—K. T. COMPTON

Here and There

Cornell University Symposium on the Structure of Metallic Phases

By E. U. CONDON, *Princeton University*

One hundred and fifty physicists and metallurgists enjoyed the hospitality of the Cornell University department of physics from July 1 to 3 at a symposium on the structure of metallic phases, the third annual symposium to be conducted at Cornell. The program opened with an address of welcome by Dr. E. E. Day, Cornell's new president, which coming at 9:30 A.M. on July 1 was Dr. Day's first official act as president of Cornell.

Order-disorder transitions in alloys, the study of which was inaugurated by the basic paper of Bragg and Williams, was the principal theme of the first day of the conference. Professor J. C. Slater gave a lucid review of the basic ideas in this field, which was followed by a paper by Professor J. G. Kirkwood who has made a more accurate calculation of the free energy function than was known hitherto.

In the simplest case one deals with a crystal lattice in which there are two kinds of sites, say X and Y, as for instance the cube corners and the cube centers in a body-centered cubic lattice, and is concerned with an alloy of equal numbers of A and B atoms. Let it be supposed that the atomic interactions are such that the state of lowest energy is that in which all A atoms are in X sites and all B atoms in Y sites. This will be the stable condition at low temperatures and is called the state of complete order. At any temperature above absolute zero the stable state is given by that which minimizes the free energy, $U-TS$, where U is internal energy, T absolute temperature and S entropy.

As entropy is related to the number of ways in which a state can be realized it is clear that states in which A atoms are distributed at random over the X and Y sites have greater entropy than the ordered state in which all A atoms are in the "right" place. As the temperature increases the contribution of the disordering entropy change to the free energy becomes more and more important so that finally the disordered state is the stable state. Bragg and Williams introduced as the measure of order the quantity, s, where $s=(R-W)/(R+W)$ in which R is the number of A atoms in the "right" places and W the number in the "wrong" places, where right means the position actually occupied in the stable low temperature form where energy rather than entropy dominates the free energy expression. Perfect order corresponds to $s=1$ and complete disorder to $s=0$.

It turns out that the internal energy as well as the entropy depends on the order s and that the order in the stable state depends on the absolute temperature. In fact there is a close analogy between the order parameter and the intensity of magnetization of a ferromagnetic substance, and the statistical mechanics shows many points of resemblance in the two cases. In consequence there is a sharp temperature, analogous to the Curie point, at which the change from order to disorder occurs and this is accompanied by an anomaly in the specific heat curve analogous to the heat effect at the Curie point of a ferromagnetic known as the magneto-caloric effect.

Continuing the discussion of order-disorder in alloys, Dr. F. C. Nix of the Bell Telephone Laboratories reviewed the experimental evidence on the copper-gold system which shows the effect of order-disorder transitions in many of its physical properties such as electrical resistivity and diamagnetic susceptibility.

An interesting review of the older theories of fusion or in general phase changes "of the first kind" (those in which there is a latent heat at the transition temperature) was presented by Professor E. R. Jette of Columbia University. In spite of a considerable literature on this subject not a great deal is definitely known about fusion and this will continue to be the case pending development of the theory of liquids to such an extent that one can calculate the free energy of the liquid phase in the neighborhood of the fusion temperature.

Of course in nearly every case where metals are used they are not in thermodynamic equilibrium at room temperature but retain their properties solely because of the slowness of the reactions which would be necessary to bring them to equilibrium. Therefore the study of the *kinetics* of reactions in alloy systems must be of the greatest importance for the science of metals. This point was stressed by Dr. R. F. Mehl of the Carnegie Institute of Technology, who presented a detailed account of the kinetics of certain phase changes occurring in steel.

On Friday the sessions were largely devoted to the theory of ferromagnetism after a general introductory review of the quantum theory of metals by Dr. F. Seitz of the General Electric Company.

An ingenious combination of the theories of order-disorder in lattices with the statistical theory of ferromagnetism was presented by Professor F. Bitter of Massachusetts Institute of Technology. This makes possible the theoretical discussion of ferromagnetic properties of alloys and in particular throws light on the circumstances in which an alloy of two paramagnetic metals may be ferromagnetic.

The remainder of the Friday session was devoted to two papers by Professor L. W. McKeehan of Yale University and Dr. R. M. Bozorth of the Bell Telephone Laboratories on the problem of ferromagnetic anisotropy in single

crystals. As McKeehan's paper has just appeared (Phys. Rev. **52**, 18 (1937)) it will not be necessary to comment on it further here. Bozorth devoted most of his time to presenting new experimental results obtained by H. J. Williams in which magnetic properties in various crystallographic directions are studied on small closed loop specimens cut in the form of parallelograms each edge of which is along equivalent crystallographic directions. He also reported that Cioffi and Williams have obtained a maximum permeability of 680,000 for a single crystal of iron in the (100) direction, the specimen having been purified from carbonyl iron by heating in a hydrogen atmosphere just below the melting point. High permeability, he pointed out, depends on (1) absence of mechanical and "chemical" strains, (2) choice of a direction of "easy" magnetization in a single crystal, (3) choice of an alloy for which the anisotropy is small, and (4) heat treatment in a magnetic field.

By combined use of all these factors a maximum permeability of 1,040,000 was obtained using a hollow rectangle of 66 permalloy grown in pure hydrogen and cut with each side parallel to a (100) direction and annealed again in pure hydrogen just below the melting point.

Saturday's session was devoted to an informal discussion of the papers of the preceding days led by Professor Slater. It was generally agreed that the conference was most valuable, that the high standard already set in two previous years was well maintained, and that the participants were deeply indebted to their hosts, the Cornell department of physics and in particular to the chairman, Professor R. C. Gibbs, for having arranged such an enjoyable and profitable occasion.

★

New Appointments

Dr. Scott W. Smith has accepted a position with the Kelley-Koett Manufacturing Company of Covington, Kentucky, as sales engineer. Dr. Smith was formerly assistant professor of physics at the University of Rochester.

★

Dr. Victor Weisskopf, of Copenhagen, who has been for the past several years a research assistant to Professor Niels Bohr and who had previously served in the same capacity with Professor W. Pauli at Zurich, has been made instructor in physics at the University of Rochester.

★

Dr. Harry Parker Hammond, head of the department of civil engineering at the Polytechnic Institute of Brooklyn, has been appointed dean of the School of Engineering at the Pennsylvania State College. A past president of the Society for the Promotion of Engineering Education, Dr. Hammond succeeds Dr. Robert L. Sackett, who retired July 1 after twenty-two years of service.

★

Dr. T. Smith Taylor is now manager of the engineering laboratory and experimental department of the Diehl Manufacturing Company, Elizabethport, New Jersey. The Diehl Company is the electrical division of the Singer Manufacturing Company located at the same address.

The American Institute of Physics takes pleasure in announcing the addition of Mr. William C. Copp to its staff. Mr. Copp's activities will be principally in the promotion of the circulation of the Institute journals and in securing advertising for *The Review of Scientific Instruments* and the *Journal of Applied Physics*.

★

Dr. Woldemar Weyl has been appointed professor of glass technology at the Pennsylvania State College, effective next January. For the past six years Dr. Weyl has been in charge of investigations on glass at the Kaiser Wilhelm Institut. During the academic year 1936–37 he has been visiting professor at the Pennsylvania State College and has given lectures at the Ohio State University, Princeton University, and the University of Illinois. He is at present in Germany.

★

At Hunter College

Miss Helen A. Messenger has been made full professor and head of the department of physics.

Dr. Duane Roller has been made associate professor of physics.

Dr. Herbert N. Otis has been made assistant professor.

Society of Rheology

Akron, Ohio, has been chosen for the ninth annual meeting of the Society of Rheology, the dates being October 22–23. Headquarters will be at the Hotel Mayflower.

A member society of the American Institute of Physics, the Society of Rheology is a relatively small group concerning itself with the flow of matter under stress. Specific properties studied include viscosity, plasticity, consistency, elasticity and others of like nature. These properties are of great interest to a wide variety of industries since many products depend for their perfection upon flow characteristics, as well as to those in academic research since many fundamental concepts can be based upon observed stress-flow relations.

Discussions in this group are invariably free and enlightening. It is felt that many physicists actively interested in rheology have failed, through oversight, to avail themselves of opportunities offered by the Society of Rheology. It is hoped that these physicists will plan to attend the Akron meeting.

The program of papers is now in preparation. Titles and abstracts (not more than 300 words) should be submitted to the program chairman not later than September 15.

H. R. Lillie, *Program Chairman*,
Corning Glass Works,
Corning, New York.

Honorary Degrees Conferred

At the commencement of Yale University on June 23 the doctorate of science was conferred on Dr. John Howard Northrop, Princeton, N. J., member of the Rockefeller Institute for Medical Research, and on Dr. Ernest Orlando Lawrence, professor of physics at the University of California.

Rutgers University conferred on June 13 the degree of doctor of laws on Dr. James Rowland Angell, retiring president of Yale University, and the degree of doctor of science on Dr. Edward R. Weidlein, director and vice president of the Mellon Institute, Pittsburgh.

★

Sigma Pi Sigma

Sigma Pi Sigma, physics honor society, on June 15 installed its thirty-third chapter at the Washington Square College of New York University. The installing officer was Dr. Marsh W. White, of the Pennsylvania State College. Dr. H. C. Rentschler, director of the Westinghouse Research Laboratory, Bloomfield, New Jersey, was received into the society as an honorary member following the installation and spoke at the first open meeting of the chapter that evening on the subject, "Recent Developments in Photoelectricity."

Dr. C. H. Robertson recently completed a lecture tour of eight chapters of Sigma Pi Sigma at Miami University, the University of Kentucky, Berea College, the University of Chattanooga, the College of William and Mary, the University of Richmond, West Virginia University and the Ohio State University. The subject of the series was "Gyroscopes and Boomerangs."

★

Westinghouse at the World's Fair

The Westinghouse Company in signing its contract announced its intention to present in a highly dramatic way to visitors to the Fair the part the company will play in "The World of Tomorrow," which is the animating spirit of the exposition. The contract calls for an Electrical Production Building with a floor space of 10,922 sq. ft.

Extensive plans have already been made for its exhibit which "will include a scientific presentation of the way in which research and development work in the last fifty years will affect mankind and its affairs in the next half century to come. It will show not only the relationship of electricity and its development to man's concerns, but their future contribution to his health, wealth and well-being. . . . There will be displays of new expansions of the electrical field such, for instance, as those which have brought about new conveniences as well as necessities—air-conditioning in all its phases, the production of ultra-violet rays for health conservation, food preservation, bacteria control, milk irradiation and other uses to which these rays have been called and will be further used in the future.

"Exhibits will be presented in the research, development and possible future trends in transportation, portraying what has been accomplished in speed and safety and what these have meant in human affairs, and also the effect of speed upon man's nervous system. Among other demonstrations the Westinghouse Company will show Diesel engine and streamlined trains, polarized glass, new transportation devices, the latest developments in radio, television and x-rays.

"The basic idea of the Westinghouse exhibit will be to demonstrate to the public the scientific manner in which power is being applied to man's needs and the tremendous effect that this scientific application will have on mankind's entire future existence."

★

Dr. Honda Receives Prize

The noted Japanese research scientist, Dr. Kotaro Honda, maker of supermagnetic steels and nonrusting steels of very low expansion with heat changes, is the first recipient of the newly created "Cultural Order of the Rising Sun." The new academic order is considered as a sort of Japanese Nobel Prize with which outstanding scientists of the country can be publicly honored.

As far back as 1916 Dr. Honda, now professor of Tohoku Imperial University and director of the Research Institute for Iron and other Metals, at Sendai, Japan, invented the famous "K.S." steel which has been used the world over in ignition magnetoes of automobiles, airplanes, radios and ship's compasses. In 1922 he helped develop a self-hardening magnetic steel and alloys of this same steel in 1930. In 1931 he directed research on steels which contained aluminum and in 1933 was able to produce nonrusting invar steel. Invar steel is the special variety of this metal which has a remarkably low coefficient of expansion that makes it invaluable in measuring steel tapes and other places where the change of length with temperature fluctuations cannot be tolerated.

Science Service, May 19, 1937

★

Television at the New York World's Fair

David Sarnoff, president of the Radio Corporation of America, and Grover Whalen, president of the 1939 New York World's Fair, have signed an agreement whereby television will be given a public demonstration by the Radio Corporation of America and the National Broadcasting Company at the World's Fair which is dedicated to "The World of Tomorrow."

By terms of the agreement, the Radio Corporation of America will construct on the Fair Ground in New York City an ultra-modern building which will house a complete exhibition of all branches of the radio art and its developments. Facilities will be provided for practical demonstration of all aspects of modern radio and television.

This building, linked directly with the NBC television transmitter on the Empire State Building, will televise

outstanding World's Fair events, and will bring to visitors, for the first time in radio history, joint demonstrations of the marvels of sound and sight broadcasting.

★

Awards of the Lalor Foundation

The Lalor Foundation, organized in 1935 for the advancement of scientific research, has issued a statement announcing the recipients of its awards for the academic year 1937–38. These are the first grants made by the foundation and comprise four fellowship awards of $2500 each for research in chemistry.

JAMES ENGLISH, JR., Yale University, research assistant at the California Institute of Technology, to continue research at the institute on the isolation and constitution of certain hormones promoting plant growth.

LELAND JOHN HAWORTH, PH.D., University of Wisconsin, instructor of physics at the university, to work in the research laboratory of physical chemistry at the Massachusetts Institute of Technology on the magnetic properties of materials at very low temperatures.

PHILIP ALBERT LEIGHTON, Ph.D., Harvard University, associate professor of physical chemistry at Stanford University, on leave of absence to conduct research in England and at Harvard University on the properties of free atoms and radicals produced during chemical and photochemical reactions.

EARL ALBERT LONG, Ph.D., Ohio State University, instructor in chemistry at the University of California, to conduct research at the University of California on the properties of radioactive sodium and radioactive phosphorus.

Two additional candidates were recommended for awards, namely, Dr. Eric G. Ball, associate professor of physiological chemistry at the Johns Hopkins University, and Dr. Nelson R. Trenner, instructor in chemistry at Princeton University. Dr. Ball was simultaneously appointed to a fellowship from the John Simon Guggenheim Foundation, which he has accepted. Dr. Trenner has withdrawn in order to accept a permanent research appointment.

★

Research Corporation Awards

The Research Corporation of New York has awarded, through the Stevens Institute of Technology, plaques and the sum of $2500 each to Professor Percy W. Bridgman, of Harvard University, and to Professor Ernest O. Lawrence, of the University of California, in recognition of their research in physics. The presentation was made at a dinner in New York City, presided over by Elon Huntington Hooker, chairman of the executive board of the Research Corporation, at which Dr. Harvey N. Davis, president of Stevens Institute, and Dr. Karl T. Compton, president of the Massachusetts Institute of Technology, were the speakers.

Science, June 11, 1937

★

Guggenheim Fellowship

Dr. Alfredo Baños, Jr., professor of theoretical physics in the faculty of physical and mathematical sciences of the National University of Mexico was awarded a renewal of his Latin-American fellowship of the Guggenheim Foundation to continue studies in the field of theoretical physics, with emphasis on the theory of cosmic radiation, at the Massachusetts Institute of Technology.

Preliminary Physics Program

Réunion International de Physique et Chemie et Biologie
Paris—September 30 to October 9

Special lecturers

PROFESSOR P. DEBYE, Kaiser Wilhelm Institut fuer Physik, Berlin. **Temperatures in the Neighborhood of Absolute Zero.**

PROFESSOR BOHR, Institut for Teoretisk Fysik, University of Copenhagen. **Nuclear Mechanics.**

Cosmic rays

PROFESSOR SIR P. M. S. BLACKETT, University of London. **The Nature of Cosmic-Ray Particles.**

PROFESSOR L. CLAY, University of Amsterdam. **The Penetration of Cosmic Rays into Matter.**

PROFESSOR G. LEMAITRE, Université de Louvain. **Cosmic Rays and the Earth's Magnetic Field.**

PROFESSOR E. REGENER, Technische Hochschule, Stuttgart. **Absorption of Cosmic Rays.**

Molecular physics

PROFESSOR M. POLANYI, University of Manchester. **Deformation of Solids.**

Nuclear physics

PROFESSOR W. BOTHE, Giessen University. **Spectroscopy of the Atom Nucleus.**

PROFESSOR J. D. COCKCROFT, Cambridge University. Subject to be determined.

PROFESSOR SCHERRER, Eidg. Technische Hochschule, Zurich. **Measurement of the Yield of Neutrons in the Reaction D + D = He + *n*.**

PROFESSOR F. JOLIOT-CURIE, Collège de France, Paris. Subject to be determined.

Low temperatures

PROFESSOR W. J. DE HAAS, University of Leyden. **Recent Progress in the Domain of Low Temperatures.**

Physical chemistry

PROFESSOR V. HENRI, Université de Liège. **Predissociation.**

DR. F. LONDON, Collège de France, Paris. **Theory of Valence in Quantum Mechanics.**

PROFESSOR N. PARRAVANO, University of Rome. **Formation and Properties of Oxides.**

PROFESSOR W. ALBERT NOYES, JR., Brown University, Providence, Rhode Island. **Primary Processes in Photochemical Reactions.**

Biophysics

PROFESSOR N. W. TIMOFEEFF-RESSOVSKY, Kaiser Wilhelm Institut fuer Hirnforschung, Berlin. **Mechanism of Mutation and the Structure of Genes.**

PROFESSOR H. J. MULLER, New York. **Biological Effects of Radiation.**

PROFESSOR J. B. F. HALDANE, University College, London. **Genetic Analysis of Natural Population.**

★

Conference on Conduction

An informal conference on "The Conduction of Electricity in Solids" was held at the H. H. Wills Physical Laboratory, University of Bristol, under the joint auspices of the Physical Society and the University of Bristol, on July 13–16. Several morning and afternoon discussions were arranged. Among those who took part in the discussions are: Professor R. W. Pohl (Göttingen), Dr. J. H. de Boer (Eindhoven), Professor Borelius (Stockholm), Professor W. L. Bragg, Dr. C. H. Desch, Professor G. I. Finch, Dr. E. T. S. Appleyard and Professor J. E. Lennard-Jones. Further information can be obtained from Professor A. M. Tyndall or Professor N. F. Mott, H. H. Wills Physical Laboratory, The University, Royal Fort, Bristol, 8, England.

Nature, May 22, 1937

New Nonmagnetic Ship

A new nonmagnetic ship with which world-wide measurements of the earth's magnetism can be undertaken is being built by the British Admiralty. The new vessel, to be known as the *S. S. Research*, will carry on the work performed for twenty years by the *S. S. Carnegie* of the Carnegie Institution of Washington. The *Carnegie* was destroyed by an explosion in the South Seas in November, 1929, when it had nearly completed a 20-year research program of investigating the secular changes in magnetism which make possible the correction of mariners' charts for compass variations throughout the world. The *Research*, it is planned, will fill in the gaps left in the *Carnegie's* program.

Necrology

Dr. W. T. Mather, professor of physics at the University of Texas, died suddenly on June 14 at the age of seventy-two years. He had been a member of the faculty for forty years.

★

Ambrose Swasey, of Cleveland, died at his summer home in Exeter, New Hampshire, June 15, 1937. A biography of Dr. Swasey will appear in a forthcoming issue of the *Journal of Applied Physics*.

Innovations in Instruments

New Plug-In Instruments Need No Panel

New, low-cost, detachable electrical measuring instruments for general industrial use are announced by Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

The detachable instrument consists of two main units, first a socket or mounting device which is provided with electrical connection jaws, and second, the instrument mechanism mounted on a plate having electrical connection blades on the back and enclosed in a weatherproof housing of glass. The instrument unit is arranged to be plugged into the socket automatically completing all electrical connections between the jaws in the socket and the blades on the instrument. The two units are then sealed together with a tamperproof sealing ring forming a weatherproof unit which may be used either indoors or outdoors as desired.

Direct advantages of the plug-in instrument for industrial use include (1) socket provides its own switchboard eliminating costly panels, wiring and mounting details, (2) various instruments can be plugged in the same socket to obtain volts, amperes, watts, power factor, kilowatt hours, etc., and (3) sockets can be installed and sealed off providing convenient outlets for future installation of instruments or making connections for portable analyzers for periodic testing.

Detachable instruments are available in a.c. ammeters self-contained up to and including 75 amperes. For larger currents a current transformer is used with a 5-ampere detachable instrument. Single and polyphase wattmeters are available self-contained up to and including 20 amperes and 115 volts. For higher ratings current transformers are used, and the potential circuit for higher voltages is supplied with external resistors or transformers. d.c. ammeters are available up to and including 30 amperes self-contained beyond which a line of Type "G" shunts is available for larger currents using a 50 millivolt d.c. ammeter.

A line of both d.c. and a.c. voltmeters is also provided in ranges from 150 to 750 volts self-contained d.c. and 150 to 600 volts self-contained a.c.

New Ultra-High Frequency Tube

Especially designed for use in ultra-high frequency or short wave service, a new oscillator and amplifier tube has been announced by the Westinghouse Electric and Manufacturing Company. Some of the main fields of application in which this tube will be used, due to its unique characteristics, are for therapy, radio, and other high frequency purposes.

In therapy work, in particular, it will permit higher power output to be obtained at the shorter wave-lengths than has heretofore been conveniently possible. It can be used equally well in ultra-high frequency radio transmitters, wherever a three-element radiofrequency amplifying tube of its characteristics is required.

The usual types of tube construction have been modified in this power tube by supporting the grid, filament and plate electrodes directly from short heavy rods. These support rods in turn terminate in short sturdy thimbles which may be used to connect directly with the external circuits. This tube is one of the first on which such basing has been used, although it has been used for many years on high wattage airport flood lamps where the high current carrying ability has been conclusively demonstrated.

Designated as the WL-461, this tube has the following ratings: maximum d.c. plate voltage—2000 volts; maximum a.c. plate voltage—2500 volts; and maximum plate current—250 ma. The filament voltage is 5 volts and the filament current is 11½ amperes. The maximum over-all length is 7½ inches.

Some of the New Books

The Scientific Basis of Illuminating Engineering. PARRY MOON. Pp. 608+xii, Figs. 290. McGraw-Hill Book Company, New York, 1936. Price $5.00.

The book provides an excellent treatment of this branch of applied physics. The quantitative side is emphasized throughout, and various methods are presented for calculating and measuring light intensity, luminous flux, illumination, and color. The author is well aware of the unsatisfactory nature of the usual definitions of footcandle and candlepower, and defines these terms through a precise operation using the spectroradiometric curve, the standard visibility function, and a numerical factor to change light-watts into lumens. The author seems to have little patience with the inaccurate, ambiguous statements often found in the literature and gives many "horrible examples" for the student to correct. There is a chapter on the newer developments in vapor lamps which discusses their spectra and luminous efficacies. The chapter on built-in lighting for interiors contains many illustrations of current practice.

It is interesting to note what the author does with the controversial question as to what constitutes a proper amount of illumination. He presents graphically the results of various studies in regard to contrast sensitivity and visual acuity. The engineer is to use these to obtain the minimum illumination which will be adequate for any given purpose. At low levels, e.g., for road lighting, landing fields, etc., this is perhaps a satisfactory procedure, though the desired level of seeing is not given; apparently it is to be specified by someone else. However, at high levels, there are many people who have a visual acuity of not more than unity, and cannot see perceptibly better out-of-doors on a bright day than they can at ten footcandles indoors. It should also be noted that if the visual acuity curve were plotted on a linear scale instead of on a logarithmic scale, it would be apparent that visual acuity rises at an almost insignificant rate (for all practical purposes) above about ten footcandles. Why should one mask the slowness of this rise by using a logarithmic scale? The only reason given by the author is that the range of illuminations is very wide. Accurate calculations of illumination seem to lose some of their importance when it is not clear what final result is to be aimed at.

The book really lives up to its title and deserves the attention of everyone interested in lighting. The text is very well illustrated by many excellent drawings and graphs and there is an adequate bibliography at the end of each chapter. The appendix, as well as the text, contains many useful tables and charts.

JOSEPH VALASEK
University of Minnesota

Wireless Engineering. L. S. PALMER. Pp. 544+xii, Figs. 353. Longmans Green & Company, New York, 1936. Price $7.50.

This book might be considered as a revision of the author's book *Wireless Principles and Practice*, published in 1927, but since a considerable amount of new material has been added, it has been considered appropriate to present the text under a new title.

After a short introductory chapter on properties of waves and the nature of the electromagnetic spectrum, the general properties of oscillating circuits and circuit elements are discussed, together with an elementary description of the use of antennas and radiating systems. General circuit theory for both continuous and discontinuous excitation is somewhat inadequately presented under the title of "Special Circuits." Included in this section are coupled circuits, recurrent networks and resonant conditions, as well as antenna systems for duplex operation. An excellent treatment of general vacuum tube theory is next presented, in which a great amount of theory has been skilfully condensed into a comparatively small space. General problems of design and a short description of manufacturing methods are also presented.

A chapter devoted to a description of spark, arc and alternator methods of transmission is inserted between the general tube theory and the treatment of tube applications. It seems to this reviewer that, while this section might have been considered desirable from the standpoint of completeness, such material has been so thoroughly covered in so many other texts, its inclusion, at the expense of more modern and less well understood material not treated or treated but briefly in this text, is not justified. An example of such exclusion of important material is found in the next chapter of fifty-four pages, on "Three Electrode Valve Oscillators," devoted almost entirely to self-excited oscillators and with only a page of piezoelectric oscillators and only five pages on circuits for frequencies above 15 megacycles.

In the next chapter, the author has not followed the example of so many writers who have seemed to feel that electromagnetic radiation theory is beyond the comprehension of the average electrical engineer, but has given an excellent presentation of the electromagnetic field theory and its application to antenna systems and transmission phenomena. This chapter, together with the last chapter on "Directional Wireless," is the outstanding feature of the book.

Exclusive of the final chapter just mentioned, the remainder of the book discusses detection, amplification and wireless telephony. Much of this material is descriptive, and not always descriptive of modern practice. Here again the reviewer feels that the discussion of such items as coherers and magnetic, capillary, electrolytic and crystal

detectors might have been omitted in favor of a more extended consideration of other material. The single-button carbon, hot-wire and magnetophone are the only types of microphones mentioned and those only in a descriptive sense. Modulation is considered very briefly and then only in reference to modulated oscillators, except for one paragraph on modulated power amplifiers. Conditions for class B and class C operation are not mentioned as such, and the particular conditions for class A operation only casually. Voice frequency reproducing and amplification systems have inadequate consideration. One exception to these criticisms is found in a short but excellent analysis of the phenomena of "beats" which is usually incorrectly or inadequately treated in most texts on radio engineering. No mention is made of newer types of electronic devices.

The concluding chapter on "Directional Wireless" is a valuable discussion of methods used to secure directional patterns for both transmitting and receiving systems. Both theory and examples of practice are well combined to give a clear picture of the present status of such systems.

On the whole, the book is rather disconcerting as to sequence and emphasis of material. As mentioned before, much of the material is concerned with obsolete though perhaps fundamental material, at the expense of important theory representing present practice. The viewpoint is thoroughly British, the author having scrupulously avoided using such terms as "radio," "vacuum tube," "antenna," etc., and practically all photographs are of British equipment and installations.

However, the sections on radiation, antenna systems and certain phases of vacuum tube theory and practice are so well presented that the book may be recommended without reserve for engineering students as well as the practicing radio engineer.

J. R. MARTIN
Case School of Applied Science

Among our Contributors

Mr. Richard Hopkins was born in East Pepperell, Massachusetts, 1914. He was graduated from Brown Unisity in 1935 with the degree of Sc.B. in Mechanical Engineering. From September 1935 to the present he has been a member of the instructing staff at the Harvard Graduate School of Engineering. He received the degree of Master of Science in Mechanical Engineering from Harvard University in June, 1937.

Dr. Mayo D. Hersey is also a contributor to this issue. A photograph and biography of Dr. Hersey appears on page 350 of the May issue of this journal.

Dr. Ludo K. Frevel was born May 31, 1910 at Frankfort-on-Main, Germany, and has been living in the United States for the past fourteen years. He received his Ph.D. in physical chemistry from Johns Hopkins University in 1934 and held a National Research Fellowship (1934–1936) at the California Institute of Technology. At present he is a research chemist in the x-ray and spectroscopy department of the Dow Chemical Company, Midland, Michigan.

Professor Karl S. Van Dyke received his Ph.D. from Chicago in 1921. Prior to this he studied at Wesleyan and then joined the Development and Research group at the American Telephone and Telegraph Company. Since leaving Chicago he has taught physics at Wesleyan, becoming professor in 1928. His chief work has been in the field of piezoelectric resonators, problems of high frequency vibrations and of viscosity of solids and gases.

Miss Elizabeth Schickele has received degrees from Des Moines University and Iowa State College and was for some years connected with the engineering staff of the Long Lines Division, American Telephone and Telegraph Company.

Percy H. Carr was born in Gaffney, S. C., September 22, 1904. He was educated at Furman University, the University of North Carolina, and Cornell University where he discovered the electrographic effect. Although he has worked in the research laboratory of General Electric he has been connected since 1930 with the Iowa State College physics department where he is in charge of instruction in photography.

Contributed Original Research

Note on the Indexing of Powder Photographs*

LUDO K. FREVEL
The Dow Chemical Company, Midland, Michigan

(Received June 15, 1937)

By taking two successive Debye-Scherrer-Hull pictures of a powder specimen at two different temperatures, one obtains on a single film a direct temperature shift of the diffraction pattern of the substance. An interval of 150°C or greater will generally suffice to produce easily measurable temperature shifts that can be related to the anisotropy of a crystalline substance. A systematic treatment of the various crystal systems has shown that the first four systems (cubic, tetragonal, hexagonal, and orthorhombic) can be indexed in a straightforward manner. Two cases of the monoclinic system: (1) $\partial\beta/\partial T=0$ and (2) $\alpha_b/2=(1/b)(\partial b/\partial T)>\alpha_a>\alpha_c>\cot\beta\partial\beta/\partial T$ can be solved without time-consuming mathematical calculations.

THE feasibility of finding a solution for the quadratic form of Debye-Scherrer-Hull patterns has been limited to cubic crystals and to the simpler structures with tetragonal or hexagonal symmetry. It is true, mathematical methods[1, 2, 3] have been proposed to solve the case of three or more parameters; however, practical efforts to apply these devices have proved very laborious and unsatisfactory. Yet in view of the simplicity and general applicability of the powder method, it would be worth while to simplify the indexing of powder photographs of tetragonal and hexagonal substances and, moreover, to extend the simplification to orthorhombic and monoclinic crystals.

In order to supplement the information gained by accurate spacing measurements, it is proposed to record on one and the same film a direct temperature shift[4] of the diffraction pattern of a substance by taking two successive exposures, each at a constant temperature. An interval of 150°C or greater will generally suffice to produce easily measurable temperature shifts that can be related to the anisotropy of a crystalline substance. A systematic treatment of the various crystal systems will serve to elucidate this relation.

The simplest case to be considered is the cubic system for which the quadratic form can be written

$$\lambda/2=a\sin\theta/(h^2+k^2+l^2)^{\frac{1}{2}}. \qquad (1)$$

Since for any given reflection h, k, l, and λ are constant, we obtain upon differentiation of (1) with respect to temperature as the independent variable

$$-\cot\theta_{hkl}d\theta_{hkl}=da/a=\alpha_a dT, \qquad (1.1)$$

where dT is the temperature interval and is taken positive. The sign of $d\theta$ accordingly is negative for expansions and positive for contractions. $\alpha_a=(1/a)(\partial a/\partial T)_P$ is the linear coefficient of thermal expansion. Hence, in addition to the usual criterion for any two reflections

* This paper was presented in part at the 1937 American Physical Society Meeting in Washington, D. C., Phys. Rev. **51**, 997 (1937).

[1] C. Runge, Physik. Zeits. **18**, 509 (1917).

[2] A. Johnsen and O. Toeplitz, Physik. Zeits. **19**, 47 (1918).

[3] F. Wever, K. W. Inst. f. Eisenforschung **4**, 67 (1922).

[4] The shutter method proposed by the author is a convenient way of recording direct shifts of interference lines. L. K. Frevel, Rev. Sci. Inst. **6**, 214 (1935).

from a cubic crystal; namely,

$$\sin^2\theta_1/\sin^2\theta_2=(h_1^2+k_1^2+l_1^2)/(h_2^2+k_2^2+l_2^2), \quad (1.2)$$

we have the independent test that $\cot\theta d\theta$ is a constant for all reflections.

For a tetragonal crystal, reflections of the type $(hk0)$ can be indexed like a cubic pattern. The relations analogous to (1.1) and (1.2) are

$$-\cot\theta_{hk0}d\theta_{hk0}=da/a=\alpha_a dT, \quad (2)$$

$$\sin^2\theta_1/\sin^2\theta_2=(h_1^2+k_1^2)/(h_2^2+k_2^2). \quad (2.1)$$

For all other reflections only higher orders of a particular reflection belong to the same value of $\cot\theta d\theta$; thus, the general relations

$$-\cot\theta_{n(hkl)}d\theta_{n(hkl)}=\frac{[(h^2+k^2)\alpha_a/a^2+l^2\alpha_c/c^2]dT}{[(h^2+k^2)/a^2+l^2/c^2]}, \quad (2.2)$$

$$\sin^2\theta_1/\sin^2\theta_2=n_1^2/n_2^2, \quad (2.3)$$

where n_1 and n_2 are the respective orders of the reflection (hkl). Now if $\alpha_a>\alpha_c$

then

$$\frac{da}{a}=-\cot\theta_{hk0}d\theta_{hk0}>\frac{\frac{h^2+k^2}{a^2}\cdot\frac{da}{a}+\frac{l^2}{c^2}\frac{dc}{c}}{\frac{h^2+k^2}{a^2}+\frac{l^2}{c^2}}=$$

$$-\cot\theta_{hkl}d\theta_{hkl}>dc/c=-\cot\theta_{00l}d\theta_{00l}, \quad (2.4)$$

where h, k, l are arbitrary integers. The converse is true if $\alpha_c>\alpha_a$.[5] Evidently inequality (2.4) combined with Eq. (2.1) immediately serves to select all those reflections of a tetragonal pattern which depend either only on a or only c. Therefore, it is possible to calculate either c/a, $n(c/a)$ or $(1/n)(c/a)$; and with one of these axial ratios known, it is a simple matter to index the remaining reflections with the aid of an accurate large scale Hull-Davey chart for tetragonal crystals.

The assignment of indices to a hexagonal pattern is carried out in the same manner as for the tetragonal system. The relations (2), (2.1), (2.2), (2.3) and (2.4) have the following respective analogs:

$$-\cot\theta_{hk0}d\theta_{hk0}=da/a=\alpha_a dT, \quad (3)$$

$$\frac{\sin^2\theta_1}{\sin^2\theta_2}=\frac{h_1^2+h_1k_1+k_1^2}{h_2^2+h_2k_2+k_2^2}, \quad (3.1)$$

$$-\cot\theta_{n(hkl)}d\theta_{n(hkl)}=\frac{\left[\frac{4(h^2+hk+k^2)\alpha_a}{3a^2}+\frac{l^2\alpha_c}{c^2}\right]dT}{\frac{4(h^2+hk+k^2)}{3a^2}+\frac{l^2}{c^2}}, \quad (3.2)$$

$$\sin^2\theta_1/\sin^2\theta_2=n_1^2/n_2^2, \quad (3.3)$$

$$-\cot\theta_{hk0}d\theta_{hk0}>-\cot\theta_{hkl}d\theta_{hkl}>$$

$$-\cot\theta_{00l}d\theta_{00l}, \quad (3.4)$$

if $\alpha_a>\alpha_c$.

The temperature shifts of an orthorhombic pattern are correlated by the following relations

$$-\cot\theta_{n(hkl)}d\theta_{n(hkl)}=\frac{\left(\frac{h^2\alpha_a}{a^2}+\frac{k^2\alpha_b}{b^2}+\frac{l^2\alpha_c}{c^2}\right)dT}{\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}}, \quad (4)$$

$$\sin^2\theta_1/\sin^2\theta_2=n_1^2/n_2^2, \quad (4.1)$$

$$-\cot\theta_{h00}d\theta_{h00}>-\cot\theta_{hkl}d\theta_{hkl}>$$

$$-\cot\theta_{00l}d\theta_{00l}, \quad (4.2)$$

if $\alpha_a>\alpha_b>\alpha_c$.[6] An interchange of a, b, and c will carry with it a corresponding interchange of h, k, l. Inequality (4.2) expresses the fact that the reflections $(h00)$ have the largest value of $(-\cot\theta d\theta)$; and those of type $(00l)$, the least value. Therefore with the ratio of c/a known, or a multiple or submultiple thereof, we can index directly reflections of type $(h0l)$ with the aid of an accurate large-scale Hull-Davey chart for the tetragonal system. Inasmuch as only the

[5] The possibility $\alpha_a=\alpha_c$ yields the degenerate case $-\cot\theta_{hkl}d\theta_{hkl}=\alpha_a d\Gamma=\alpha_c dT$; $\sin^2\theta_1/\sin^2\theta_2 \neq (h_1^2+k_1^2+l_1^2)/(h_2^2+k_2^2+l_2^2)$ for h, $l\neq 0$.

[6] Two degenerate cases can arise: (1) $\alpha_a=\alpha_b>\alpha_c$,

$$\frac{h_1^2+k_1^2}{h_2^2+k_2^2}\neq\frac{\sin^2\theta_{h_1k_10}}{\sin^2\theta_{h_2k_20}}\neq\frac{h_1^2+h_1k_1+k_1^2}{h_2^2+h_2k_2+k_2^2}$$

and (2) $\alpha_a=\alpha_b=\alpha_c$,

$$\sin^2\theta_1/\sin^2\theta_2\neq(h_1^2+k_1^2+l_1^2)/(h_2^2+k_2^2+l_2^2)$$

for prism and pyramid reflections.

TABLE I.

n	h^2/a^2	k^2/b^2	l^2/c^2	$4\sin^2\theta/\lambda^2$	$-\cot\theta d\theta$	(hkl)
1	$1/a^2$	$1/b^2$	$1/c^2$	$4\sin^2\theta_1/\lambda^2$	$-\cot\theta_1 d\theta_1$	$h_1k_1l_1$
2	$4/a^2$	$4/b^2$	$4/c^2$	$4\sin^2\theta_2/\lambda^2$	$-\cot\theta_2 d\theta_2$	$h_2k_2l_2$
3	$9/a^2$	$9/b^2$	$9/c^2$	$4\sin^2\theta_3/\lambda^2$	$-\cot\theta_3 d\theta_3$	$h_3k_3l_3$
n	n^2/a^2	n^2/b^2	n^2/c^2	$4\sin^2\theta_n/\lambda^2$	$-\cot\theta_n d\theta_n$	$h_nk_nl_n$

reflections $(h0l)$ of the chart are involved it is less confusing to use a special chart from which the pyramid reflections have been eliminated. The reflections $(hk0)$ can be indexed on the same diagram by moving a logarithmic record of all the spacings (except of type $(00l)$) along one of the straight lines with known indices; e.g. (200), until a coincidence is discovered for the said prism reflections. A specialization of (4.2); namely,

$$-\cot\theta_{hk0}d\theta_{hk0} > -\cot\theta_{hkl}d\theta_{hkl}, \qquad l\neq 0, \quad (4.3)$$

$$-\cot\theta_{hk0}d\theta_{hk0} > -\cot\theta_{0k0}d\theta_{0k0}, \qquad h\neq 0, \quad (4.4)$$

$$-\cot\theta_{hk0}d\theta_{hk0} > -\cot\theta_{h0k}d\theta_{h0k} >$$

$$-\cot\theta_{0kl}d\theta_{0kl}, \qquad h, k, l\neq 0, \quad (4.5)$$

will aid in the identification of those reflections most probably of type $(hk0)$. Inasmuch as reflections of type $(h0l)$ have been identified, the next largest value of $(-\cot\theta d\theta)$ belongs to a reflection $(hk0)$. By this direct procedure we can ascertain very quickly the ratio b/a; and consequently the indexing of the remaining prism face reflections becomes straightforward.

There remains the assignment of indices to the pyramid reflections. Inasmuch as the lattice constants are known, there is little difficulty in solving the quadratic form

$$4\sin^2\theta/\lambda^2 = h^2/a^2 + k^2/b^2 + l^2/c^2. \quad (4.6)$$

One of the simpler analytical procedures to find suitable values for h, k, l of (4.6) is to prepare a table schematically represented by Table I.

By inspection of the first five columns of Table I we immediately can set upper values to any of the indices to be entered in column 6. Furthermore, the values of $(-\cot\theta d\theta)$ then serve as a guide in the selection of the most probable indices to satisfy (4) and (4.6).

Although it does not appear practical to set down a general method for indexing powder patterns of monoclinic crystals, nevertheless certain special cases merit attention. For a monoclinic lattice, the analytical expression of Bragg's law is given by expression (5).

$$\lambda/2 = d\sin\theta = \frac{\sin\theta}{\left(\dfrac{h^2}{a^2\sin^2\beta} + \dfrac{l^2}{c^2\sin^2\beta} - \dfrac{2hl\cos\beta}{ac\sin^2\beta} + \dfrac{k^2}{b^2}\right)^{\frac{1}{2}}}. \quad (5)$$

The temperature shifts of the various reflections can be grouped in accordance with the Eqs. (5.1) and (5.2).

$$-\cot\theta_{n(hkl)}d\theta_{n(hkl)} = \frac{\left[\dfrac{h^2\alpha_a}{a^2} + \dfrac{l^2\alpha_c}{c^2} - \dfrac{hl(\alpha_a+\alpha_c)\cos\beta}{ac} + \dfrac{k^2\alpha_b\sin^2\beta}{b^2}\right]dT}{d^2\sin^2\beta} + \frac{\left[1 - \dfrac{k^2}{b^2} + \dfrac{hl}{ac\cos\beta}\right]\cot\beta d\beta}{d^2}, \quad (5.1)$$

$$\sin^2\theta_1/\sin^2\theta_2 = n_1^2/n_2^2. \quad (5.2)$$

Inasmuch as the expression $1/d^2(k^2/b^2 + hl/ac\cos\beta)$ is not definite, we cannot arrange the values of $(-\cot\theta d\theta)$ according to a general inequality corresponding to (4.2). However, it is of interest to consider the following special cases.

Case I. $\alpha_a > \alpha_b > \alpha_c$ and $d\beta = 0$. Then

$$-\cot\theta_{h00}d\theta_{h00} > -\cot\theta_{hkl}d\theta_{hkl} > -\cot\theta_{00l}d\theta_{00l}. \quad (5.3)$$

The integers h, k and l are arbitrary and an interchange of a, b and c carries with it a corresponding interchange of h, k, l. It is evident that the problem of indexing the prism face reflections $(hk0)$ and $(0kl)$ reduces to the orthorhombic case already treated in detail. In order to identify the reflections $(h0l)$, we make use of a modification of the Hull-Davey method. Since we know the quantities b, $a\sin\beta$, $c\sin\beta$, we can plot the logarithm of the spacing

$$d_{h0l} = \frac{a\sin\beta}{(h^2 + a^2l^2/c^2 - 2ahl\cos\beta/c)^{\frac{1}{2}}} \quad (5.4)$$

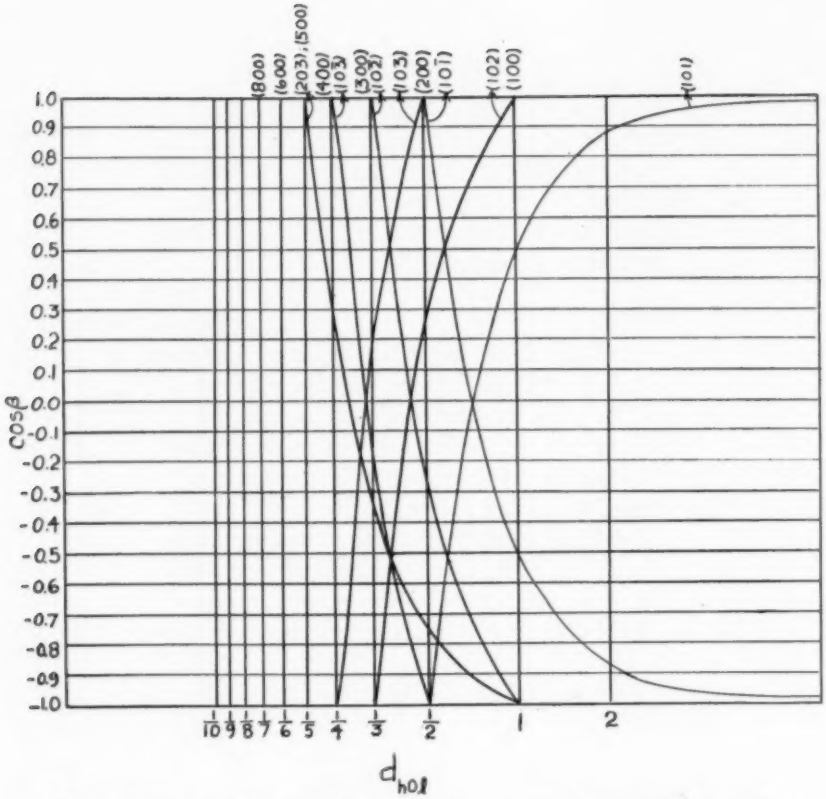


FIG. 1. A graph of the variation of the interplanar spacings d_{h0l} with the value of $\cos\beta$.

as a function of $\cos\beta$. Fig. 1 gives a plot corresponding to the case $a/c=1$. In nearly all of the structure determinations that have been carried out, it is found that the first four orders of the following reflections: (101), $(10\bar{1})$; (102), $(10\bar{2})$; (201), $(\bar{2}01)$ will include the more prominent prism reflections $(h0l)$. Hence an accurate calculation of these six first-order[7] reflections, in general, will be sufficient for the identification of the simpler prism reflections $(h0l)$ inasmuch as higher orders of these six reflections can be constructed graphically with little effort. To index the prism reflections $(h0l)$ we move a logarithmic record of the unidentified spacings and of the known pinacoid spacings $(h00)$ and $(00l)$ along one of the straight lines with known indices; e.g., (200), until an accurate coincidence is found. The established value for $\cos\beta$ thus permits the indexing of the pyramid reflections in a manner similar to that of the corresponding case for the orthorhombic system.

[7] $\log d_{n(h0l)}=\log d_{h0l}-\log n$.

Case II. $(\alpha_b/2)>\alpha_a>\alpha_c>\cot\beta(d\beta/dT)$. These conditions restrict (5.1) to the following inequalities.

$$-\cot\theta_{00l}d\theta_{00l}<-(1/2\rho)(\partial\rho/\partial T)_P{}^{8}$$
$$<-\cot\theta_{h00}d\theta_{h00}<-\cot\theta_{0k0}d\theta_{0k0}, \quad (5.5)$$

where ρ is the density of the crystalline substance. Moreover, the largest value of $(-\cot\theta d\theta)$ is less than $\alpha_b dT+2|\cot\beta d\beta|$. Although there is no simple direct procedure for uniquely identifying the basal reflections $(0k0)$, we first select those sets of $(-\cot\theta d\theta)$ greater than $(1/2\rho)\times(\partial\rho/\partial T)_P$. The set with the largest value of $(-\cot\theta d\theta)$ is then tentatively taken as the $(0k0)$ set. To test if this assumption is true, we try to index the prism reflections $(hk0)$ and $(0kl)$ in the same manner as in Case I. If this is not possible, we must proceed to the other per-

[8] $-\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_P=\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P=\alpha_a+\alpha_b+\alpha_c+\cot\beta\left(\frac{d\beta}{dT}\right)$.
The variation of density with temperature is determined experimentally.

missible sets of $(-\cot\theta d\theta)$. Having found the correct set and having satisfactorily indexed the reflections $(hk0)$ and $(0kl)$, we are in a position to index the prism face reflections $(h0l)$ according to the direction for Case I. Thus, it is possible to calculate b, $a\sin\beta$, $c\sin\beta$ and $\cos\beta$ and thus to find indices for the remaining unidentified reflections.

The restriction imposed by Case II is somewhat arbitrary; however, for layer structures similar to graphite[9] the thermal expansion normal to the layers is usually very much greater than in the layer. Consequently a knowledge of the different linear coefficients of expansion can aid in the structure determination of such crystals.

The simplified method of indexing a powder pattern may be illustrated conveniently by a numerical example. We shall use the experimental data of E. A. Owen and E. L. Yates,[10] who have determined the lattice constants of zinc metal at different temperatures—their values for 0°C are: $a=2.6582$A, $c=4.9290$A; for 150°C, $a=2.6639$A, $c=4.9742$A. Table II lists the temperature shifts of the Debye-Scherrer-Hull pattern of Zn powder subjected to a temperature change of 150°C. The calculation was made for CuK radiation and an effective camera radius of 100.00 mm.

To find the indices (hkl), we proceed in the following manner.

(1) Since the values of $\cot(\theta+\Delta\theta/2)\Delta\theta$ differ for the various reflections, it is seen by inspection that the pattern is that of a noncubic substance.

(2) If the crystal be tetragonal and $\alpha_a>\alpha_c$, then the $\sin^2\theta$ values of set (b) should form a continued ratio of squares; i.e.,

$$\sin^2\theta_1/\sin^2\theta_n=l_1^2/l_n^2=1:3:4.$$

This condition cannot be fulfilled. The case $\alpha_a<\alpha_c$ requires that the $\sin^2\theta$ values of the set (b) satisfy the criterion

$$\sin^2\theta_1/\sin^2\theta_n=(h_1^2+k_1^2)/(h_n^2+k_n^2)=1:3:4.$$

Evidently this requirement also cannot be satisfied.

(3) The crystal is hexagonal and α_a is greater than α_c, then the values of $\sin^2\theta$ belonging to set (b) should be in the ratio of squares. This is not the case. However, the condition $\alpha_a<\alpha_c$ satisfies the $\sin^2\theta$ ratio tests for the hexagonal system. Accordingly the axial ratio of c/a is equal to $0.927n=0.927$, 1.854, $\cdots$ or $0.927/n=0.927$, 0.463, $\cdots$. It is readily found that the value 1.854 fits the various observed spacings on an accurate Hull-Davey chart from which all of the remaining indices may be obtained directly.

TABLE II.

(hkl)	ΔS mm	$-10^3\cot\left(\theta+\frac{\Delta\theta}{2}\right)\Delta\theta$	SET	$\sin^2\theta_1:\sin^2\theta_2:\sin^2\theta_3$
002	1.19	9.14 largest	*a*	1 : 4 : 9
100	0.30	2.15 least	*b*	1 : 3 : 4
101	0.54	3.40	*c*	1 : 4
102	1.11	5.40	*d*	1 : 4
103	1.89	6.76		
110	0.61	2.16	*b*	
004	2.90	9.14	*a*	
112	1.30	3.72		
200	0.77	2.16	*b*	
201	0.95	2.51		
104	3.00	7.53		
	3.01			
202	1.48	3.40	*c*	
	1.48			
203	2.49	4.45		
	2.50			
105	5.08	8.02		
	5.09			
114	3.78	5.90		
	3.81			
204	4.77	5.40	*d*	
	4.84			
006	9.35	9.13	*a*	
	9.53			

(hkl) are the indices of the various planes; ΔS = the difference of the Debye-Scherrer ring diameters measured in mm; θ = the Bragg angle; $\Delta\theta$ = the temperature shift measured in radians.

This method of indexing should be of value to the metallurgist who is frequently concerned with the problem of determining whether a polycrystalline material consists of a single phase or of several phases. The temperature shifts of the various phases may readily serve to discriminate one diffraction pattern from other superimposed patterns. Moreover, if a single phase has been properly indexed, it is a simple matter to ascertain the linear coefficients of thermal expansion. To the crystal structure investigator, this proposed method of indexing powder photographs should be of interest inasmuch as for layer structures, such as a graphite, the linear expansion normal to the layers is usually much greater than for other crystallographic directions.

[9] M. Hirata, Sci. Pap. Inst. Phys. Chem. Research (Tokyo) **15**, 219 (1931).
[10] Phil. Mag. **16**, 606 (1933).

Notes on the Electrographic Effect

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A portion of a metal surface was protected by means of a stencil during exposure in air to 100 kilovolt cathode rays. An attempt was then made to "develop" an image of the stencil on the metal surface by the action of some chemical or other reagent. Results confirm previous reports that water vapor is helpful if not essential to satisfactory development. On the metals, silver, copper, tin, zinc, lead, brass, and bismuth, the inorganic materials investigated for developing properties were superior to the organic materials tried. The image was not developed directly by electroplating by any method yet tried on any material except carbon. Attempts to produce an image in relief by first developing it in the ordinary way and then electroplating the specimen, failed except when anthraquinone was used as the developer. However, results by this method were uncertain. Cadmium vapor as a developer produces images of low relief.

THIS study was initiated in the hope that a practical method of engraving by means of cathode rays could be found. Although this aim has not been accomplished as yet, much has been learned concerning the chemical behavior of metal surfaces exposed to cathode rays in an atmosphere of air at atmospheric pressure.

A metal surface which has been exposed to cathode rays exhibits properties differing from those of a metal surface not so treated. Thin foils become less transparent to light, and, under long exposure, quite opaque.[1] A wrinkling and discoloration of beryllium and gold has been observed when these metals were used as anticathodes in x-ray tubes.[2, 3] For example, a plate of gold may be fitted with a stencil through which cathode rays strike the surface. If the gold is treated after exposure to mercury vapor under suitable conditions, the image of the pattern is made visible. Specimens subjected to short exposures show no image before development even when examined with optical instruments. The developed image fades slowly in air, but, if protected from chemical vapors and light, it will remain in good condition for several years—and perhaps longer.

Any phenomenon of the type just described will hereinafter be termed electrographic. The invisible change produced by the cathode-ray exposure will be referred to as the latent electrographic image, or merely as the latent image. The process of rendering the latent image visible will be called development, and the reagent which brings about development will be described as a developer.

As a preliminary survey, the investigation here described was undertaken for the purpose of answering the following questions:

1. What materials are the best developers of the latent image on certain chosen metals?

2. Can the latent image be rendered in relief (a) by electroplating immediately after exposure? (b) by electroplating the image produced by previous development in an inorganic or organic developer? (c) by taking advantage of any chemical differences that might exist in a suitably developed image? (d) by development in a vapor which condenses to a hard solid?

The source of cathode rays was a tube of the hot cathode type possessing a window of aluminum foil stretched over a brass grid. The tube was excited by half-wave rectified a.c. having a peak voltage of 100,000 volts. The current through the window which had an area of approximately 1 cm^2 was less than 0.1 m. Specimens with stencil attached were clamped close to the window and exposed in air for two thirty-second periods separated by a rest interval of ten seconds. The surfaces were prepared immediately before raying by rubbing with fine sandpaper and rouge paper.

Inorganic Vapors as Developers

Experiments were carried out on silver, copper, tin, zinc, lead, brass, all in sheet form and cast bismuth. The developers investigated were mercury, sulphur, bromine, chlorine, iodine, hydrogen chloride, nitric acid vapor, sulphuric acid vapor, ammonia, sulphur dioxide, and hydrogen sulphide. Suitable reagents for producing the

[1] P. H. Carr, Rev. Sci. Inst. **1**, 711 (1930).
[2] Webster, Clark, and Hansen, Proc. Nat. Acad. Sci. **14**, 679 (1928).
[3] W. W. Nicholas and C. C. Malmberg, Nat. Bur. Stand. J. Research **8**, 61 (1932).

developing agent in vapor form were placed in an open dish and gently heated. The specimen was held in the vapor close to the surface of the mother liquid. Development required from 5 to 20 minutes. Water vapor from the breath is not only a good developer itself, but a certain degree of humidity aids the developing action of other vapors. Drying sometimes prevented successful development entirely. The materials mentioned all proved to be successful developing agents except hydrogen sulphide and sulphuric acid vapor. Images of excellent contrast were produced by all developers (except H_2SO_4 and H_2S) on silver, tin, and copper. Images were faint on lead and bismuth and fair on brass. Results with zinc were uncertain; the images were good if they appeared at all. The best results were obtained with the following combinations of developer and metal: iodine or mercury with silver, iodine with tin; and iodine, sulphur, or mercury with copper. The amount of water vapor present, and the temperature of both the vapor and the specimen were varied in a qualitative way, but this yielded little information as to the controlling conditions. However, the ease of development increased somewhat if the temperature of the specimen was a few degrees cooler than room temperature.

Samples were developable four or five hours after raying if kept in air reasonably free from chemical vapors; and, if placed in a calcium chloride desiccator, they could be developed the next day. However, the air of the room developed images on both silver and copper within a few hours.

Results obtained with inorganic vapors while fairly certain were not uniform. One characteristic, however, appeared to be common. During the early stages of development, the rayed part was in an inactive condition and remained unaffected by the developing vapor; but, upon continued treatment, showed greater activity than the unrayed areas. Appearances indicated chemical union in some cases and mere condensation in others.

Organic Vapors as Developers

Acetic acid, oleic acid, stearic acid, formaldehyde, acetone, camphor, paradichlorbenzene, anthraquinone, rosin, and Japan wax were tried as developers as described above. All proved worthless with the single exception of acetic acid which may be distinguished from the others mentioned by its greater ease of ionization. In this respect, it resembles the inorganic developers. Development with the other organic compounds again failed in the presence of a brush discharge from a Tesla coil to further ionization. This could be ascribed to the high coefficient of recombination of the ions produced at atmosperhic pressure. The next step, therefore, was to effect development in a vertical closed glass tube connected to a mechanical vacuum pump which operated during the development process, care being taken that no grease vapor entered the tube. Burner and Tesla coil were applied to the outside. With this arrangement, anthraquinone developed images on tin, silver, and copper, the latter being by far the best. Camphor and paradichlorbenzene developed fair images on copper. The other compounds proved complete failures.

Electroplating Directly without Previous Development

Rayed but undeveloped pieces of silver, copper, and tin were electroplated in aqueous and alcoholic solutions of their respective salts; silver nitrate, copper sulphate, hydrated stannous chloride, and anhydrous stannic chloride (liquid used undiluted). No images appeared. However, specimens of graphite rayed and electroplated in an aqueous solution of copper sulphate showed the pattern, the copper depositing slightly more rapidly on the rayed regions before electrolytic deposition completely covered the specimen.

Electroplating after Development in Inorganic Vapors

Rayed specimens of tin and copper were developed with iodine and sulphur, respectively, to a point of heavy deposition on the unrayed areas, but just short of visually perceptible deposition on the rayed areas, and were then electroplated in aqueous solution of their respective salts, hydrated stannous chloride, and copper sulphate. The peeling off of the developer in the electrolyte prevented the hoped for differential plating. Thinness of the developing

layer of sulphur prevented its fusion into a hard coat. The thickness of other films was not considered sufficient to justify similar attempts.

Electroplating after Development in Organic Vapors

Deposits of nonconducting organic compounds should be excellent protectors of those areas which are not to be electroplated. One specimen of copper developed in anthraquinone to the point described in the preceding paragraph and electroplated in aqueous copper sulphate solution received a thin plating on the rayed areas.

Attempts to Produce Images in Relief by Removing the Compound Formed by the Developer on the Rayed Area without Affecting the Compound Formed on the Unrayed Area

Because of the marked difference in reaction of rayed and unrayed portions, it seems possible that different compounds are formed on the two areas and that their dissimilar chemical properties could be used to produce a relief. Compounds formed on the basis of different valences might result, but more likely the difference is due to formation of the hydrated and anhydrous forms of the same compound. This was tested on the basis of the following chemical relations: solubilities of stannous and stannic iodides in sulphuric acid; decomposition temperatures of hydrated and anhydrous cupric chlorides, and their solubilities in ether and ammonium chloride. Specimens developed until an over-all deposit appeared were held in the vapor of the reagent, or gently heated. No differential action was observed.

Production of Images in Relief by the Use of a Metal Vapor as Developer

Since mercury vapor developed the latent image, it is reasonable to assume that metals of higher melting points might behave similarly, the deposit hardening into permanent relief. The tube previously described, with filings of clean cadmium as the developer, was evacuated and heated by resistance furnace. The cadmium sublimed at a temperature below 400°C and developed images on silver, tin, copper, and brass particularly well on the two latter. However, the process was irregular. In some cases, development proceeded slowly and evenly, while in other cases, periods of activity alternated with intervals of inactivity. Sometimes the deposit was chiefly on the rayed portions, and at other times the reverse was true. The deposit was hard and smooth but did not possess the desired differential thickness. Tin as a developer was also studied in a similar manner with occasional success. However, it was harder to control than cadmium. The investigation of this method of development is still in its early stages.

Collected Results on Viscosity of Lubricants under Pressure. I. Fatty Oils*

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In this paper the principal results of experiments on the viscosity of lubricating oils under high pressure, other than mineral oils, have been reduced to the same units and collected for comparison. The investigations reviewed are those of the American Society of Mechanical Engineers; J. H. Hyde at the National Physical Laboratory of Great Britain; S. Kiesskalt at the Technische Hochschule, Karlsruhe, Germany; and Y. Suge at the Institute of Physical and Chemical Research, Tokyo, Japan. Viscosity-pressure-temperature data are given for eleven different oils.

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Historical Introduction

AMONG the earliest experiments on viscosity under high pressure were those of Professor Barus at Brown University on marine glue.[1] These were the first in which viscosity was expressed as a function of both pressure and temperature. The increase in viscosity of lubricating oils under pressure was later investigated by a Committee of the American Society of Mechanical Engineers, and discussed in a series of papers[2] beginning in 1916.

These experiments were begun at Harvard University in cooperation with P. W. Bridgman, utilizing the ball-and-slanted-tube type of viscometer invented by A. E. Flowers, often described as the rolling-ball viscometer. The final results obtained with this equipment, up to a pressure of 4000 atmospheres or kg/sq. cm, were reported by Hersey and Shore[3] at the 1927 Annual Meeting of the A. S. M. E. In the meantime the pressure range available for viscosity observations had been more than doubled by Professor Bridgman with the development of a new type of apparatus for the study of pure liquids. Arrangements were made with Professor Bridgman and Dr. Robert V. Kleinschmidt to extend the A. S. M. E. investigation to higher pressures. Kleinschmidt's results were described in a further report,[4] also presented at the 1927 Annual Meeting and reprinted in 1928. These observations were based on a falling-body method.

Hyde's results[5] (capillary method) were published in 1920, Kiesskalt's[6] (falling body) in 1927, and Suge's[7] (falling sphere) in 1932 and 1933. A more complete bibliography would include Bridgman's experiments on various liquids of interest for lubrication research, particularly glycerine, kerosene, oleic acid, and water; experiments by Hersey and Snyder on capillary flow of castor oil and plastic greases; also by several investigators on the viscosity of oils containing dissolved gases under pressure, and by R. B. Dow on compressibility. New experiments are already in progress in American and foreign laboratories.

Coordination of high pressure viscosity data has been recognized as a part of the program of the A. S. M. E. Special Research Committee on Lubrication. The present paper, it is hoped, may serve both as a progress report on the foregoing program and as a step toward obtaining discussion and cooperation from rheologists. It is difficult to compare results immediately because of the diversity of units and methods adopted for expressing the effect of pressure on viscosity. Hence, our main task in the present report is to collect and tabulate the published data after reduction to some one system of definitions and units. Mathematical coordination will follow in due course.

This report is limited to viscosity observations as such, without comment regarding their significance for lubrication. The lubrication viewpoint has been discussed elsewhere by Kiesskalt[6] and others.[3, 8]

Extent of Data Available

The American tests referred to include four fatty oils,[9] castor, lard, rapeseed, and sperm,[10] in addition to the compounded and mineral oils. The British tests include four fatty oils, castor, rapeseed, sperm, and trotter or neatsfoot, in addition to mineral oils; the German, three fatty oils, linseed, neatsfoot, and peanut; the Japanese, six—camellia seed, castor, hemp, horse, rapeseed, and whale. These four investigations are

[1] Carl Barus, "Isothermals, Isopiestics, and Isometrics Relative to Viscosity," Am. J. Sci. [3] **45**, 404–410 (1893).

[2] M. D. Hersey, J. Wash. Acad. Sci. **6**, 525–530 (1916); Mech. Eng. **41**, 537 (1919); **35**, 315 (1923); and subsequent papers.

[3] M. D. Hersey and H. Shore, "Viscosity of Lubricants Under Pressure," Mech. Eng. **50**, 221–232 (1928).

[4] Special Research Committee on Lubrication, Fourth Report, Trans. A. S. M. E., APM-50-4, 1–5 (1928); Mech. Eng. **50**, 682 (1928).

[5] J. H. Hyde, "On the Viscosities and Compressibilities of Liquids at High Pressures," (a) Proc. Roy. Soc. **A97**, 240–259 (1920); (b) Rep. Lubricants and Lubrication Inquiry Com., Dept. Sci. Indust. Res., London, App. 7–9, pp. 80–90 (1920).

[6] S. Kiesskalt, "Untersuchungen über den Einfluss des Druckes auf die Zähigkeit von Oelen und seine Bedeutung für die Schmiertechnik," Forschungsarbeiten **291**, Berlin: VDI (1927), 14 pp.

[7] Y. Suge, "Viscosity of Oil Under Pressure" (in Japanese), Bull. Inst. Phys. Chem. Res., Tokyo, (a) **11**, 877–894 (1932); (b) **12**, 643–662 (1933).

[8] M. D. Hersey, *Theory of Lubrication* (New York: Wiley, London: Chapman & Hall, 1936), pp. 12, 34–36, 56, 92–94, 124, 126, 135, 136, 143.

[9] G. S. Jamieson, *Vegetable Fats and Oils* (New York: Chemical Catalog Company, 1932; A. C. S. Monograph Series No. 58).

[10] A liquid wax commonly classed as a fatty oil; see p. 16 of reference 9.

TABLE I. *Pressure limits, American tests. Temperature °C, followed by pressure in atmospheres.*

(a) FATTY OILS*
1. Castor (A-I): 21° *800*, 25° *1500*, 39° *3300*, 60° *3000*, 88° *3300*, 100° *2700*, 135° *1800*. (A-II): 25° *4100*, 40° *4800*, 75° *9500*, 80° *7400*.
2. Lard (A-I): 22° *1700* (S), 100° *3500*. (A-II): 25° *2700* (S), 40° *4200* (S), 75° *6500* (S).
3. Rapeseed (A-II): 25° *2200* (S), 40° *1100*, 75° *1500*.
4. Sperm (A-II): 25° *1100* (S), 40° *2100* (S), 75° *5100* (S).

* Data on (b) compounded and (c) mineral oils reserved for later publication.

TABLE II. *Pressure limits, British tests. Temperature 40°C; pressure in atmospheres.*

(a) FATTY OILS	
1. Castor: *1160*	3. Sperm: *1100*
2. Rapeseed: *1100*	4. Trotter: *1260*

TABLE III. *Pressure limits, German tests. Temperature °C; pressure in atmospheres.*

(a) FATTY OILS	
1. Linseed: 20°, 50°, 80° to *600*.	
2. Neatsfoot: *Do.*	3. Peanut: *Do.*

TABLE IV. *Pressure limits, Japanese tests. Temperature °C; pressure in atmospheres; J-I = 1932, J-II = 1933 report.*

(a) FATTY OILS
1. Camellia Seed (J-I): 18° *2000*.
2. Castor (J-I): 18° *2000*. (J-II): 1° *600*, 10° *1300*, 30° *1700*, 40° *2000*, 50° *1800*, 65° *Do.*, 105° *1100*, 124° *1600*.
3. Hemp (J-I): 18° *1900*.
4. Horse (J-I): 18° *1500* (S). J(II): 1° *400* (S).
5. Rapeseed (J-I): 18° *2000*. J(II): 1° *700* (S), 10° *1600*, 40° *1800*, 60° *Do.*
6. Whale (J-I): 18° *1900*. (J-II): 1° *700* (S), 10° *1200*, 40° *2000*, 60° *Do.*

identified below by the symbols *A*, *B*, *G*, and *J*, respectively.

The original observations are in the form of data for isothermal curves, the temperature being held constant while the pressure is varied. The approximate maximum pressures corresponding to the respective isotherms are given in Tables I–IV.

The condition known as apparent solidification under pressure is indicated by (*S*) and reported below for horse, lard, rapeseed, sperm, and whale oils. In the literature reviewed, apparent solidification has also been reported for certain compounded oils, as well as for liquid paraffin, and petroleum oils containing sufficient paraffin wax.

In Table I the numerals I and II are used to identify the Hersey and Shore tests and Kleinschmidt tests, respectively. The 21° isotherm for castor oil (I) is obtained by averaging observations at 20° and 22°. The 88° isotherm is a weighted mean from observations at 79° and 92°. The 135° isotherm is derived from observations at 133° and 140°. Under both A-I and A-II the results obtained from two samples of castor oil have been averaged together.

The foregoing particulars can be more vividly presented with the aid of a series of pressure-temperature diagrams, one for each of the oil samples listed above, 17 diagrams in all. Such a diagram is constructed with the pressure axis vertical and temperature axis horizontal. A heavy vertical line is drawn at the location corresponding to each experimental temperature, and extending upward for a distance representing the maximum pressure reached. From Tables I–IV it is seen that there would be 11 such lines for the American tests on castor oil, one for the British and 9 for the Japanese; or 21 altogether. Each of these lines on the pressure-temperature diagram may be interpreted as the projection of an isothermal viscosity-pressure curve. A space model of the viscosity-pressure-temperature surface might be constructed for any one oil by erecting a sheet of cardboard on each of the isothermal projections as a base, with its upper edge cut to the shape of the appropriate isothermal curve. The 21 isotherms for castor oil, together with one isobar from each laboratory, are plotted in logarithmic form in Fig. 1. The extent of the data on fatty oils available from the four published investigations here reviewed is indicated by the fact that 58 isotherms would be required to complete the picture.

METHODS OF REPRESENTATION

The chief difficulty in comparing and applying the published data, aside from identification of mineral oils, has been due to lack of uniformity in the methods of numerical and graphical representation. Fig. 1 with the definitions and formulas given below will indicate the methods adopted for the present report. The four charts assembled in Fig. 1 represent the principal

results on castor oil obtained in the respective investigations.

These charts are intended to show in the simplest manner how the relative viscosity is affected by pressure and temperature. The pressure scale will be found at the bottom and the temperature scale at the top of each chart. The pressure, p, is expressed in metric atmospheres (1 atmos. = 1 kg/sq. cm = 14.22 lb./sq. in.); the temperature, t, in °C.

The left-hand scale gives the logarithm of the relative viscosity R_1, sometimes called the *isothermal* relative viscosity. By definition R_1 denotes the ratio of the viscosity Z at any temperature and pressure to the viscosity Z_1 at the same temperature but at atmospheric pressure, i.e.,

$$R_1 = Z/Z_1. \tag{1}$$

For example: Chart A-I shows that the isothermal relative viscosity at 39°C has increased tenfold ($\log R_1 = 1.0$) at a pressure of about 1800 atmos.

The right-hand scale gives the logarithm of the relative viscosity R_0, which may be called the *atmospheric* relative viscosity. By definition R_0 denotes the ratio of the viscosity Z_1 at atmospheric pressure and any temperature, t, to the viscosity Z_0 at that pressure, but at the standard or *normal* temperature t_0. Thus

$$R_0 = Z_1/Z_0. \tag{2}$$

For example: Chart A-I shows that the atmospheric relative viscosity of castor oil dropped from one down to one-tenth when warmed up from 25° to about 65°C, since $\log R_0 = 0$ ($R_0 = 1.0$) at $t = t_0 = 25$°C and $\log R_0 = \bar{1}$ ($R_0 = 0.10$) at $t = 65$°C approximately. The atmospheric relative viscosity may be found from the curve marked $p = 1$ on each chart, referring to the temperature scale at the top and the $\log R_0$ scale at the right.

The charts above described are laid out in substantially the same form as Fig. 7 of the *Theory of Lubrication*,[8] where, however, the temperature axis is drawn toward the left. In either system of plotting, all curves, both isotherms and isobars, would be straight lines if the viscosity-pressure-temperature relation satisfied Eq. (17), page 34, of the reference cited.[8]

While the *isothermal* and *atmospheric* relative viscosities are well adapted for use in reporting experimental data, a third ratio needed in practical applications is the *general* relative viscosity or *viscosity ratio*, defined by

$$R = Z/Z_0. \tag{3}$$

When the term "relative viscosity" is used without qualification, the isothermal relative viscosity R_1 should be understood; but when the term "viscosity ratio" is used without qualification, as in Kleinschmidt's work, it may be taken to mean the ratio R.

From (1), (2), and (3) it follows that

$$R = R_1 R_0, \tag{4}$$

and therefore

$$\log R = \log R_1 + \log R_0. \tag{5}$$

For example: to find from Chart A-I the viscosity ratio or general relative viscosity for castor oil at 100°C and 2000 atmos., we read off on the right-hand scale $\log R_0 = \bar{2}.5$ corresponding to the isobar $p = 1$ at $t = 100$°C. Then from the left-hand scale $\log R_1 = 0.75$ corresponding to the 100° isotherm at $p = 2000$ atmos. Hence by (5), $\log R = 0.75 - 2.0 + 0.5 = \bar{1}.25$; therefore $R = 0.178$. This is the value of the ratio Z/Z_0 according to Eq. (3). To obtain the absolute viscosity Z we should first know Z_0. Taking Z_0 from experimental data = 5.9 poises at $t_0 = 25$°C, we have $Z = RZ_0 = 0.178\ (5.9) = 1.05$ poises.

Complete Results for Castor Oil

The foregoing value $Z_0 = 5.9$ poises for the viscosity of castor oil at $p = 1$ atmos. and $t = 25$°C was obtained from Report A-I by reading off the values at $p = 1$ atmos. from the published smooth curves after giving triple weight to Sample No. 2 in accordance with the larger number of observations. No value of Z_0 was reported by A-II but since the samples were furnished by Hersey and Shore within a short time after the completion of their own experiments, we may safely assume in round numbers $Z_0 = 6$ poises at 25°C. The most complete Z_1 values by Hyde are apparently in Series I, page 55, of the Report, Dept. Sci. Indust. Research, 1920. Interpolating gives $Z_0 = 5.3$ poises at 25°C. No tests were made upon castor oil in the German investigation, but from the Japanese report J-II we have $Z_0 = 6.00$ poises.

In plotting Chart A-I, Fig. 1, all values were taken from the published smooth curves, averaging two adjacent isotherms when necessary. Proceeding in this manner Table V has been assembled, with the aid of which the reader can

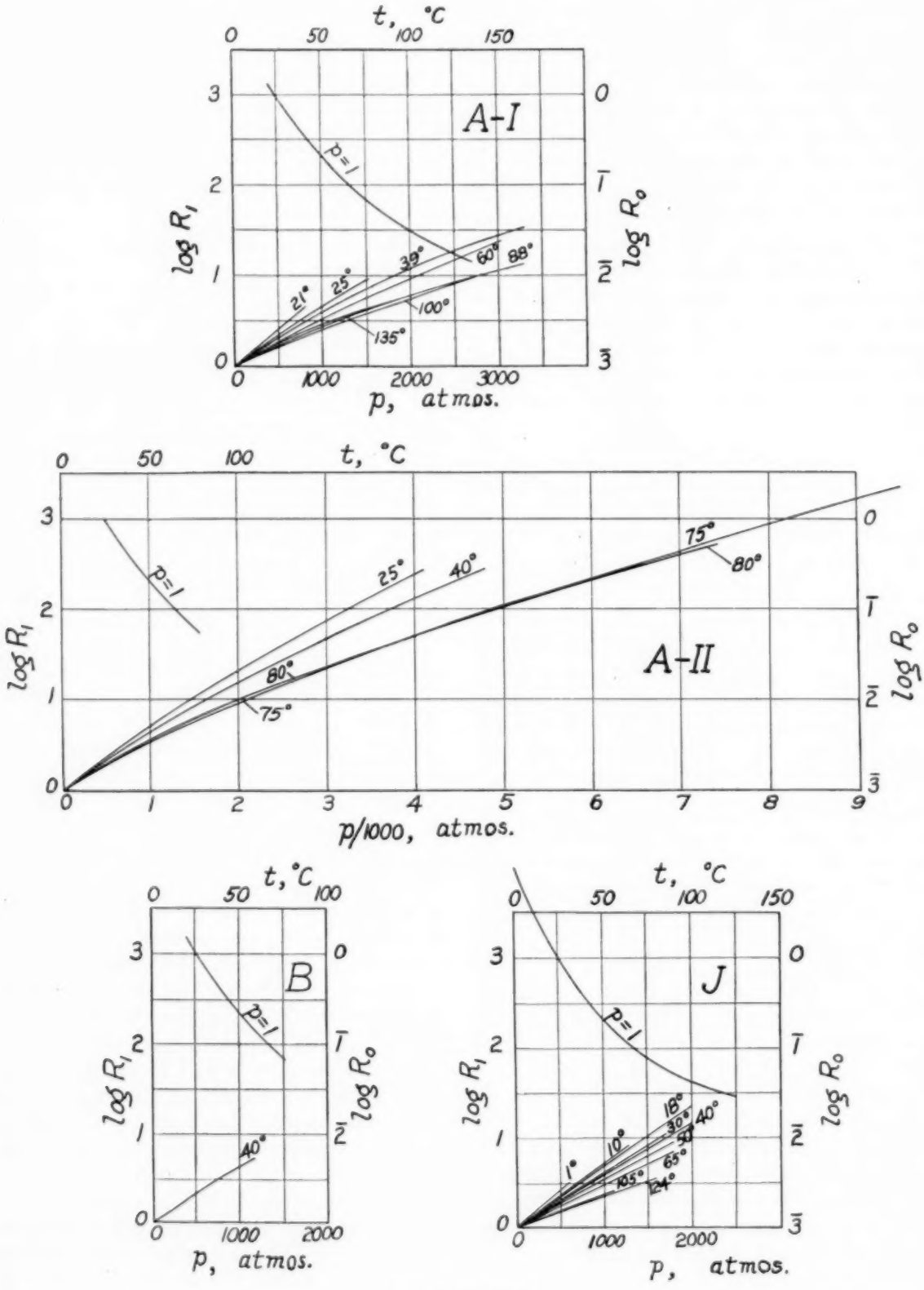

FIG. 1. Castor oil.

at any time reconstruct Chart A-I on a more open scale if desired. In this table relative viscosities are given at $p=1$, 500, and 1000 atmos., and every 1000 atmos. thereafter, with end-points at odd pressures in parentheses. In plotting Chart A-II the values of log R were taken from the published smooth curves and converted into log R_1 values by subtracting log R_0 in accordance with Eq. (5). The necessary log R_0 values are simply the log R values for $p=1$ atmos. The data so obtained are shown in Table VI.

The relative viscosities for castor oil according to Hyde,[5] from p. 89 of the Report cited are given by Table VII below, after converting from tons/sq. in. to atmospheres. Plotting-data for log R_0 for castor oil (B) from Hyde's Series I, p. 55, are given in Table VIII.

The Japanese isotherms for castor oil are plotted in Fig. 1, Chart J, from the published pressure coefficients. The log R_1 values in Table IX are for an arbitrary pressure of 1000 atmos. but graphs are limited to the actual maximum pressures; see Table 3 in Suge's paper.[7b]

We are now in a position to compare the results of the several investigations on castor oil. Selecting $p=1000$ atmos. as a basis for comparison and reading off the logarithms for 25°, 40°, and 75°C from Fig. 1 (or by interpolation from Tables V–IX) we obtain the relative viscosities recorded in Table X. It is evident that substantially identical results are obtained regardless of the type of apparatus used.

TABLE V. *Relative viscosities for castor oil (A-I).*

p, atmos.	VALUES OF log R_1 AT TEMPERATURES IN °C						
	21°	25°	39°	60°	88°	100°	135°
1	.00	.00	.00	.00	.00	.00	.00
500	.41	.33	.31	.28	.23	.22	.25
(800)	.67	—	—	—	—	—	—
1000	—	.65	.60	.52	.45	.43	.49
(1500)	—	.96	—	—	—	—	—
(1800)	—	—	—	—	—	—	.71
2000	—	—	1.08	.96	.80	.77	—
(2700)	—	—	—	—	—	1.00	—
3000	—	—	1.45	1.39	1.07	—	—
(3300)	—	—	1.53	—	1.13	—	—
log Z_1 (poises)	0.88	0.77	0.45	$\bar{1}$.85	$\bar{1}$.45	$\bar{1}$.23	$\bar{2}$.96
log R_0	0.11	0.00	$\bar{1}$.68	$\bar{1}$.08	$\bar{2}$.68	$\bar{2}$.46	$\bar{2}$.19

TABLE VI. *Relative viscosities for castor oil (A-II).*

p, atmos.	Log R_1			
	25°	40°	75°	80°
1	.00	.00	.00	.00
1000	.70	.65	.55	.57
2000	1.30	1.21	0.96	1.00
3000	1.89	1.69	1.34	1.37
4000	2.40	2.14	1.72	1.70
(4100)	2.42	—	—	—
(4800)	—	2.46	—	—
6000	—	—	2.33	2.32
(7400)	—	—	—	2.72
8000	—	—	2.95	—
(9500)	—	—	3.35	—
log R_0	0.00	$\bar{1}$.56	$\bar{2}$.82	$\bar{2}$.70

TABLE VII. *Relative viscosities for castor oil (B).*

p, atmos.	Log R_1	p, atmos.	Log R_1
1	.0000	551	0.3636
24	.0086	865	0.5623
288	.1367	1164	0.7235

TABLE VIII. *Isobar ($p=1$) for castor oil (B).*

t, °C	Log R_0	t, °C	Log R_0
21.6	.097	49.3	$\bar{1}$.332
24.7	.011	51.9	$\bar{1}$.266
(25.0)	(.000)	60.1	$\bar{1}$.101
29.7	$\bar{1}$.892	70.1	$\bar{2}$.128
39.0	$\bar{1}$.652	76.0	$\bar{2}$.819
40.5	$\bar{1}$.609	—	—

TABLE IX. *Relative viscosities for castor oil (J).*

t, °C	Log R_0	Log R_1 (1000 atmos.)	MAX. p, atmos.
1	0.973	.85	600
10	0.539	.71	1300
18	0.230	.68	2000
(25)	(0.000)	—	—
30	$\bar{1}$.834	.61	1700
40	$\bar{1}$.544	.58	2000
50	$\bar{1}$.301	.53	1800
65	$\bar{1}$.029	.48	1800
105	$\bar{2}$.661	.37	1100
124	$\bar{2}$.427	.35	1600

TABLE X. *Comparison of results on castor oil. $p=1000$ atmos.*

LABORATORY	25°C		40°C		75°C		Z_0 poises
	log R_1	R_1	log R_1	R_1	log R_1	R_1	
A-I	.65	4.5	.59	3.9	.46	2.9	5.9
A-II	.70	5.0	.64	4.4	.53	3.4	(6.0)
B	—	—	.63	4.3	—	—	5.3
J	.64	4.4	.59	3.9	.45	3.0	6.0
Mean	.66	4.6	.61	4.1	.48	3.0	5.8

Condensed Results on the Remaining Oils

Tables XI–XIV are of the same form as Tables V, VI, etc. except for obvious simplifications. Reference may be made to Tables I–IV for the end point, or pressure limit, at each temperature. The apparent solidification pressures are not necessarily as high as the pressure limits reported. The question of apparent solidification (p. 36 of reference 8) is under investigation from a rheological standpoint and should be further discussed at a later date.

Table XIV completes the task of assembling the essential results on fatty oils from the investigations herein reviewed and reducing the observations to a numerical form that will facilitate intercomparison of data from different laboratories, practical application to lubrication problems, comparison of mineral and fatty oils, and the correlation of pressure effects with other physical characteristics.

Table XI. *Logarithms of R_1, etc. (A).*

p, atmos.	Lard (A-I)[a]		Rapeseed (A-II)		
	22°	100°	25°	40°	75°
500	.38	.25	.39	—	.31
1000	.70	.46	.73	—[c]	.53
2000	—	.77	1.30[b]	—	.83[b]
3000	—	1.02	—	—	—
4000	—	1.26[b]	—	—	—
log R_0	0.05	$\bar{1}$.08	0.00	—	$\bar{2}$.90
p, atmos.	Lard (A-II)			Sperm (A-II)		
	25°	40°	75°	25°	40°	75°
500	—	—	—	.33	.33	.24
1000	.64	.60	.49	—	.60	.48
2000	1.30	1.07	.91	—	—	.87
4000	—	—	1.61	—	—	1.52
6000	—	—	2.19	—	—	—

[a] $Z_0 = 59$ cp. [b] Extrapolated. [c] Log $R = \bar{1}.76$.

Table XII. *Logarithms of R_1, etc. (B).*

Oil	Z_1, centipoises[a]		Log R_1	
	20°C	40°C	*500*	*1000*
Rapeseed	90	38	.30	.57
Sperm	34	16	.30	.55
Trotter	89	35	.35	.62

[a] Hyde, reference 5 (b), pp. 89–90, 92.

Table XIII. *Logarithms of R_1, etc. (G). Pressure, p, in atmospheres; temperature, °C; viscosity, Z_1, centipoises.*

p, atmos.	Linseed			Neatsfoot			Peanut		
	20°	50°	80°	20°	50°	80°	20°	50°	80°
500	.24	.20	.17	.27	.22	.21	.27	.24	.21
Z_1	52	18	8.3	87	26	11	83	25	10

Table XIV. *Logarithms of R_1, etc. (J). Temperature, t, °C; viscosity, Z_1, centipoises; log R_1 for $p = 1000$ atmos.*

Oil	t	Z_1	Log R_1
Camellia-Seed	18	85	.54
Castor	18	1019	.68
Hemp	18	50	.54
Horse	18	51	.56
Rapeseed	1	224	.82[a]
	10	126	.65
	18	84	.60
	40	39	.52
	60	21	.51
Whale	1	193	.65[a]
	10	113	.61
	18	79	.55
	40	38	.44
	60	22	.37

[a] Extrapolated.

Acknowledgment is made to Dr. S. Sakanishi and Miss H. P. Bell of Washington, D. C., for translations and to Winslow H. Herschel of the National Bureau of Standards and R. Bulkley of the Socony-Vacuum Oil Company for technical information. The authors are indebted to Dr. Bulkley for calling to their attention the work being done by Y. Suge at the Institute of Physical and Chemical Research. Thanks are due to the investigators cited in the text for additional information supplied by correspondence.

On the basis of the methods and results here presented, together with the earlier literature on mineral oils and other data now available,[11] it should be possible to undertake a much more systematic study of the viscosity-pressure-temperature relations for lubricating oils.

[11] R. B. Dow, "The Effects of Pressure and Temperature on the Viscosity of Lubricating Oils," J. App. Phys. **8**, 367–372 (1937).

Note on a Peculiar Case of Fracture of a Quartz Resonator

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IT is nothing novel for an experimenter driving a quartz resonator piezoelectrically to fracture the crystal at sufficient amplitude of vibration. Neither is breaking a crystal by dropping it on a concrete floor an unheard of event. The author has twice dropped a 2″ polished crystalline quartz sphere three or four feet onto such a floor. On the first occasion the sphere bounced a foot or more into the air and was caught after a single bounce. There was no evidence of fracture or damage of any sort. On the second occasion the sphere cracked and bounced but little. But to have a quartz crystal bounce hard enough from mere contact with a rigid body to hurl itself with breaking force against a cast iron wall with no appreciable fall at all is probably unusual.

In the present instance a 25 kc resonator, X-cut, Y-wave, 10 cm long with a 6 mm square section was being driven in a vacuum with 14 volts applied to silver plated contact electrodes, very close to its resonant frequency. The resonator was suspended by a very fine copper wire soldered with Wood's metal to the upper silvered surface of the crystal and a second wire was similarly fastened to the lower surface. Both wires were attached accurately at the centers of the faces, that is, at the node of motion for the fundamental longitudinal lengthwise vibration. A current of 7 milliamperes was flowing through the crystal whose electrical impedance was practically a pure resistance of 1600 ohms. Its logarithmic decrement was 2.5×10^{-5}. The electrical resonance curve of the crystal was in the process of being observed point by point and was noted to be a little unstable as resonance was approached. Such an instability appearing as a series of sudden slight shifts in the resonance frequency had been noted on a previous occasion just before the resonator had dropped loose from its suspending wire. True to form, the crystal this time dropped after a few seconds of irregularity in the resonance curve.

The crystal was contained in an evacuated vertical cast iron cylinder, about 6″ in diameter on the inside. On opening the cylinder, the crystal was found to be broken into three large pieces, with a few small chips which came from the main fractures. The present argument is concerned with the method of fracture. The suspended crystal had been but 2″ above a velvet mat at the base of the cylinder. The side walls of the cylinder were not, however, covered but were bare raw cast iron. The crystal was suspended horizontally and quite near to the vertical axis of the cylinder. The fine wire to the under side was long enough to allow the crystal to lie almost anywhere in the cylinder if the upper wire should break.

The lines of fracture divided the 10 cm crystal into three very nearly equal parts. Actually one end section was about 6 mm longer than the other two pieces. Had the crystal been vibrating at an overtone double the fundamental frequency, fractures from excessive vibration might have been expected nearer to the ends. The two end sections would then have been each about half as long as the center section. The driving source was afterwards checked for its harmonic content and this was of very small order compared with the fundamental. The fracture lines as found seem to have no relation to the mode of vibration which is such that greatest strains occur at the center of the rod.

There was a 2 in. diameter 1 in. high porcelain evaporation dish containing phosphorous pentoxide resting on the base of the container. Inspection of the crystal a day or two earlier had disclosed that the crystal was so oriented about its vertical axis of suspension that its end projected over this dish. The crystal was, however, about an inch above the dish.

From the measured current and voltage applied to the resonator at 25 kc and from its known characteristics, it was computed that the maximum velocity of vibration of either end of the quartz was about 200 cm/sec. at the time of dropping loose from the suspension. This corresponds to the velocity which the crystal would

have acquired if it had fallen four feet under gravity. If it suddenly came in contact with a very hard-surfaced rigid body, end on, and when in just the right phase of its vibration, it might have been expected to rebound as did the sphere from the concrete floor. It is believed that this is what happened. The position of a small clean-cut pile of debris and of some of the recognizable chips which it contained clearly showed that the crystal broke on being thrown against the wall of the vertical cylinder. This pile could have been placed where it was only as the crystal tried to bend itself around the curved wall. The crystal could have been thrown only by a bounce on the porcelain dish. Also, it so happens that the dish was in just such a position with respect to the suspended crystal as to make it likely that in tearing loose from its suspension the crystal should touch its end to the dish. The lower wire was presumably torn off in the bounce.

The applied voltage and the current were not sufficient to cause a fracture—at least they had been exceeded many times before with this same resonator. Nor do the lines of fracture have the characteristic pattern which broken resonators of this mode regularly show.

This may seem like a rather fantastic reconstruction of the tragedy but all other possible events have been considered and ruled out and no facts have been found which are inconsistent with the above. The only chance items are that of the phase of vibration at the instant of contact and that of the crystal's position being just such as to let it hit the rim of the dish end on as it fell. The velocity is computed from the piezoelectric constants of quarts, the dimensions of the resonator, the measured decrement, and the applied voltage.

The moral in our own experimental work is to keep all hard rigid bodies away from possible reach of a driven resonator. It may dash itself to pieces even though it has no opportunity to fall.

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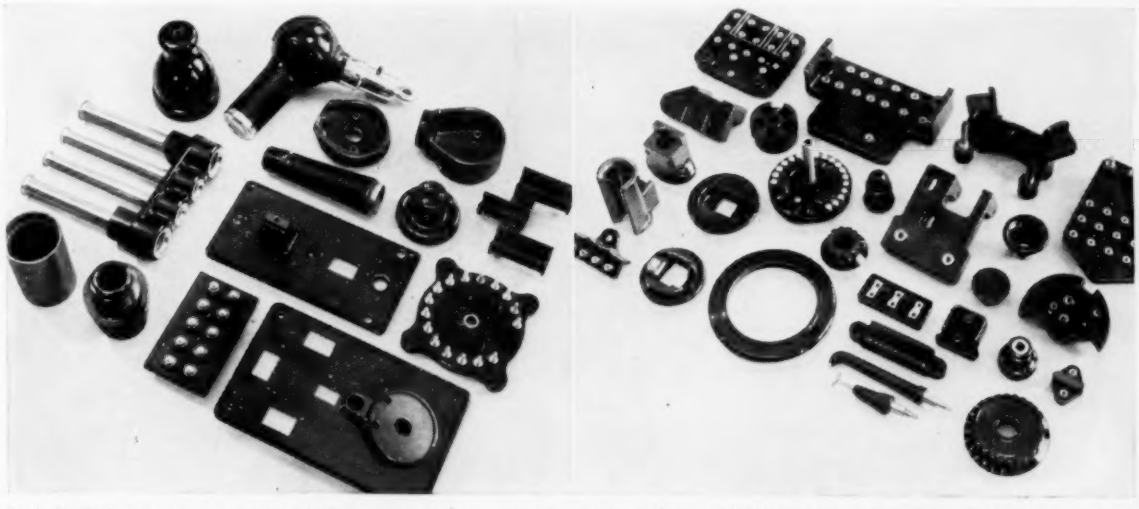

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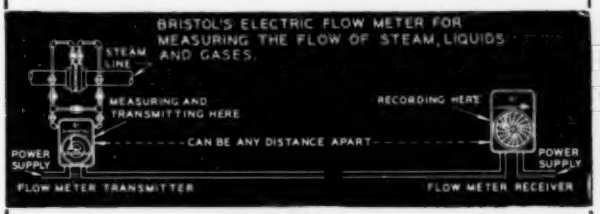
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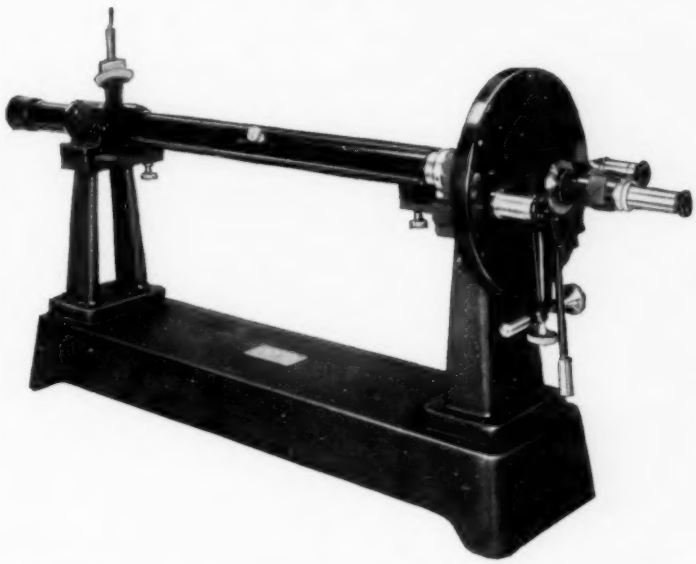

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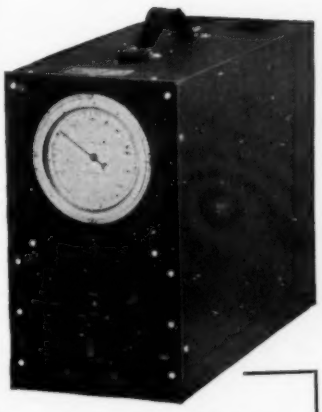

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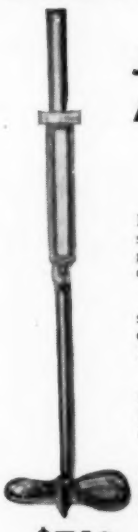

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